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University spin-off firms' struggle with openness in early knowledge relationships: in search of antecedents and outcomes

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ABSTRACT

Little is known about how young high-tech ventures create openness in their knowledge networks. This paper explores the influence of antecedent resources on openness in knowledge networks, seen as diversity in knowledge partners, and explores the impact of openness on growth. The results from 105 university spin-off firms suggest that three antecedents positively influence openness, namely, founders' prestart experience, education and innovation experience, and one negatively, namely, size of the founding team. Regarding non-linearity, there are signs of cubic influences, potentially in line with passing critical junctures. In addition, external factors tend to have no influence on openness, except for region of location. Further, shaping the right amount of openness and benefitting from it seem a struggle, as an increasing openness tends to influence growth with decreasing returns.

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1. Introduction

The trend towards open innovation has been studied extensively for established large firms, but much less where small firms are concerned (Chesbrough 2003; Chesbrough, Vanhaverbeke, and West 2006; Laursen and Salter 2006; Gassman, Enkel, and Chesbrough 2010; West and Bogers 2014; West et al. 2014; Huang et al. 2015). SMEs have been taken as the subject of study more recently, van de Vrande et al. (2009) and Lee et al. (2010) being some early examples. With the growing attention for open innovation among SMEs, also investigation of (causes of) differentiation in openness between firms became more popular (e.g. Xia 2013; Bigliardi and Galati 2016; Calof, Meissner, and Razheva 2017; Hochleitner, Arbussà, and Coenders 2017). Some studies have placed an emphasis on external factors that influence openness, like market turbulence (Chesbrough 2007) while other studies argue that the internal resources situation is more important (Barge-Gil 2010; Bigliardi and Galati 2016) or suggest a combination of internal and external factors (Drechsler and Natter 2012; Riccobono, Bruccoleri, and Perrone 2015).

This study deals with openness, viewed as being open through connecting with a diverse set of partners in knowledge and information gaining on crucial resources. The emphasis is put on diversity in knowledge partners following other studies, for example, Laursen and Salter (2006) and Huang et al. (2015). In the literature, open innovation is usually conceived of as essentially broader than openness in knowledge relationships, namely, including the innovation process and innovation activities themselves that are distributed across various partners in a network. Due to the specific focus, we only use 'openness in knowledge relationships'.

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Our study is engaged with a specific type of small firms, namely, young university spin-off firms. As such a small firm size may cause a constraining influence in the building of openness, however, as a contradictory trend in recent past, an increased adoption of openness is apparent among small firms (Xia 2013; Mina, Bascavusoglu-Moreau, and Hughes 2014; Muzzi and Albertini 2015; Hochleitner, Arbussà, and Coenders 2017). This development reflects two contrasting opinions on young and small firms' responding to challenges and threats. On the one hand, these are faced with uncertainty and risk while continuously adjusting and leveraging their capabilities to survive and reach next stage in growth (Vohora, Wright, and Lockett 2004; Mohr, Sengupta, and Slater 2010). Specific resources are missing, among others legitimacy and financial resources (Stinchcombe 1965). These circumstances cast doubt on effectiveness in creating openness in knowledge networks and resulting benefits. On the other hand, in a more optimistic view, the emphasis is put on relatively large flexibility and responsive learning by young ventures, coupled with strong opportunities for innovation due to the potential to step aside from fixed paths, and explore and acquire diversified external knowledge (Bigliardi and Galati 2016). This optimistic vision is among others known from literature on internationalisation of spin-offs. However, it is not clear how such positive capabilities are being built drawing on various antecedents, like education and prestart business experience.

Against this background, the article aims to clarify the antecedents in shaping openness in knowledge relationships and the influence of this openness on growth of the firms. This aim connects with a whole set of questions as follows. How important are antecedents for shaping openness? What is the influence of more recent experience with innovation within the firm, and which types of relationships (linear versus curvilinear) emerge when it comes to shaping more or less open knowledge relationships? And to what extent can openness be effective in enhancing growth of the firms?

A sample of 105 university spin-off firms is studied. Spin-off firms as a specific category of young ventures, are defined as independent start-ups established by university staff or graduates with the aim to commercialise knowledge developed at university (Pirnay, Surlemont, and Nlemvo 2003; Shane 2004). University spin-off firms tend to be more focussed on new technology compared to non-spin-off young firms, which makes a part of them more vulnerable in developing new markets or accessing existing markets (Klofsten 2005; Mustar, Wright, and Clarysse 2008; van Geenhuizen and Soetanto 2009; Galati et al. 2017). The article reads as follows. In section 2, the theoretical perspectives and hypotheses are discussed. Methodology aspects are in section 3. Next, results of model estimation of openness and of growth are in section 4, including various case study results. The article closes with a discussion and suggestions for future research.

2. Theory and model building

2.1. Openness in knowledge networks

Several authors connect openness directly to innovation; however, we focus on openness in knowledge relationships in itself, and measure it through diversity of partners, functional and geographical (Laursen and Salter 2006; Dahlander and Gann 2010; Leiponen and Helfat 2010; Huang et al. 2015). Diversity in knowledge relationships is seen as crucially important to university spin-offs, especially when the knowledge originates outside their own technical domain and generates complementarities, for instance, application knowledge and knowledge on access to funding and launching customers (Colombo and Grilli 2010; Drechsler and Natter 2012). Getting knowledge through different partners also provides a broader ability of sensing opportunities that enables a larger variety in strategy formulation and adaptation (Teece 2007), although too much diversity may not work beneficially due to lack of management ability (e.g. Sampson 2007). The role of antecedents in such abilities among university spin-offs is however not clear.

We approach antecedents as being mainly developed prior to start of the spin-offs through experience and education of founding team members, and partly after start, and we design a model accordingly (Teece 2007; Escribano, Fosfuri, and Tribo 2009; Visintin and Pittino 2014; Riccobono, Bruccoleri,

and Perrone 2015). Below, we discuss antecedents and phrase a set of hypotheses concerning their influence on shaping openness in knowledge networks as well as concerning the influence of openness on firm growth.

2.2. Organisational antecedents of openness

The influence of antecedents on openness can take on different patterns, linear and curvilinear ones. Broader literature on learning and sensing suggests some non-linear relationships, including growing 'lock-in' development and related 'decreasing returns' (e.g. Robbins and Judge 2011). The overall contradictory trends in literature make us phrase two types of hypotheses for the influence of antecedents on openness in knowledge networks, namely, one for a positive influence in a linear model and one for a curvilinear influence based on decreasing returns (inverted U-shape). We see two exceptions, namely concerning multidisciplinary education and participation in training, which in this study are described as 'states' in the sense of presence/absence.

Founding team size indicates the resource base at start. Theory on the size of founding teams is contradictory, with some suggesting that, when the founding team is larger, the firm in question is more receptive in learning and capable to shape diversity in knowledge networks (Davidsson, Delmar, and Wiklund 2006). However, in literature on team management, larger founding teams are assumed to increase the chance of 'social loafing', which cause the opposite effect (Robbins and Judge 2011). In general, 'social loafing' occurs when people exert less effort and perform at lower levels when working in a group, compared to working alone or as a pair. Also, larger founding teams may have a smaller need for openness in knowledge networks just because they have 'internalised' specific knowledge. According to these contradictory views, we phrase:

1a) Size of the founding team has a positive influence on openness in a linear relationship.

1b) Size of the founding team has a curvilinear influence on openness.

Likewise, the education of founding team members tends to influence a firm's learning activity. Higher education levels may increase the ability to sense new (external) knowledge through diverse partners, and thus increase openness in the networks (Colombo and Grilli 2010). However, a higher education may also cause a 'lock-in' situation based on increasing self-confidence and self-reliance (Beckman, Burton, and O'Reilly 2007; Dencker, Gruber, and Shah 2009), creating a curvilinear relationship between the level of education and openness. This leads to the following hypotheses:

2a) Education level has a positive influence on openness in a linear relationship.

2b) Education level has a curvilinear influence on openness.

Furthermore, it can be expected that founding teams with a multidisciplinary education are more open to external sources, due to their stronger ability to connect with and benefit from more different types of knowledge partners. However, multidisciplinary education in this article is limited in variation, in that it refers to a combination of technology studies and management/market studies or absence of this combination, meaning that it is impossible that a situation of 'lock-in' can be measured. Accordingly, we phrase:

3) Education diversity has a positive influence on openness.

For pre-start experience of founders, a distinction is often made between different domains of experience of founders, e.g. starting-up a firm or R&D activity, and different duration of experience (Lee et al. 2010; Visintin and Pittino 2014). In this study, we analyse the influence of experience domains and duration of experience in the same sector on openness. Beckman, Burton, and O'Reilly (2007) confirm that founding teams with diverse functional backgrounds and scope of

experience learn more efficiently, leading us to assume that, with a broad pre-start experience, encompassing heterogeneous knowledge contents, the networks are likely to be more open to different partners. However, we may also assume that larger numbers of experience domains are more difficult to handle thereby introducing non-linear trends. In a similar vein, new ventures led by managers with longer experience in the same sector can better identify opportunities of openness because they are more familiar with the industry (Colombo and Grilli 2005), which in turn will increase openness. In contrast, other studies indicate that prior start-up experience leads to a negative impact, because of emerging 'lock-in' situations based on increasing self-confidence and self-reliance, providing constraints in developing openness (Beckman, Burton, and O'Reilly 2007; Dencker, Gruber, and Shah 2009). Founders' number of experience domains and duration of experience may correlate, which in the preparation of the analysis found to be true for our dataset (a correlation of 0.63). Therefore, we only formulate hypotheses concerning number of experience domains:

4a) Founders' experience domains have a positive influence on openness in a linear relationship.

4b) Founders' experience domains have a curvilinear influence on openness.

Next, we consider experience of the firm with innovation mainly gained after firm start. Presence of R&D in firms is included in many openness studies (Barge-Gil 2010; Xia 2013; Laursen and Salter 2014; Hochleitner, Arbussà, and Coenders 2017). In a similar vein, patent-protected innovation and patent effectiveness are found to be important in existing literature, e.g. in Drechsler and Natter (2012) and Laursen and Salter (2014). Furthermore, owning patents increases visibility and legitimacy, and it improves attractiveness of the firm to other learning partners (Riccobono, Bruccoleri, and Perrone 2015). In particular, as a first mover, the firms are often involved in rapidly changing new product development, while seeking out risky opportunities as market pioneers. Accordingly, they have to stay flexible and scan a wide range of external circumstances, using different knowledge partners (Mohr, Sengupta, and Slater 2010; Hochleitner, Arbussà, and Coenders 2017). However, being one of the first in the market with an innovative product/process may make managers also 'blind' and cause 'lock-in' in knowledge interactions and routines that become quickly outdated. In the current analysis, R&D expenditure and patented knowledge together with newness of innovations are taken into account as reflecting amount of recent innovation experience. According to the above contrasting situation, we phrase:

5a) Level of innovation experience has a positive influence on openness in a linear relationship.

5b) Level of innovation experience has a curvilinear influence on openness.

With regard to training, we follow the same argumentation as for multidisciplinary education, namely, it is present or not. If certain team members have participated in market-related training, this may help to be more open to external partners, e.g. in looking for complementary knowledge on markets and sensing emerging competitors and new industrial trends (Klofsten 2005; Escribano, Fosfuri, and Tribo 2009). Training is often on demand and temporary, preventing the rise of 'lock-in' situations. This leads us to phrase:

6) Participation in market-related training has a positive influence on openness.

2.3. Control factors openness

We control for three external factors: city-region, sector type and market competition, and we control for firm size and age. The city-region refers to remote regions with a specialised and 'thin' economy (Isaksen 2015) in contrast to metropolitan regions with a larger and more diversified economy. Accordingly, a remote location and lack of local variation may trigger young ventures to adopt 'compensation' by creating high diversity in knowledge networks, e.g. including large distances (Teirlinck

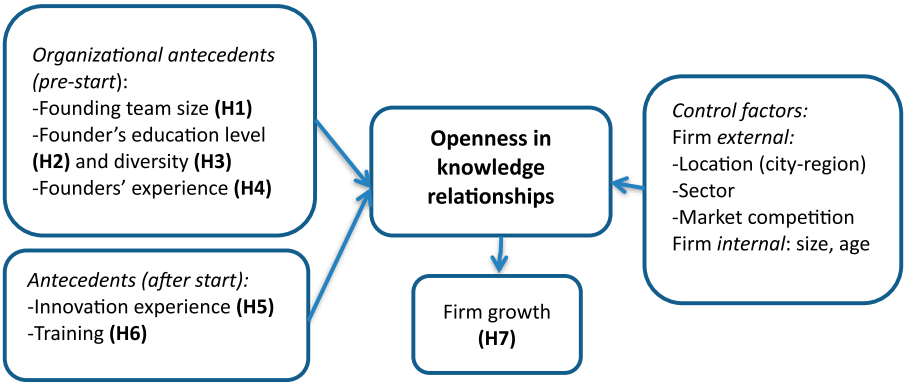

Figure 1. Research framework.

and Spithoven 2008). Otherwise, these firms strengthen internal capabilities, e.g. through enlarging their team or intensive in-house learning. Secondly, sector type emphasises the difference in learning between science-based and market-based sectors (Asheim et al. 2007). Science-based firms are often involved in radical inventions, global communities and rapidly changing environments, and presumably require a larger openness, while non-science-based firms deal more often with problem-related learning, mostly in close interaction (on the spot) with a few users/customers (Jensen et al. 2007). Also, we assume that market competition plays a role in shaping openness in knowledge networks. And finally, size and age at the time of the survey act as control factors, knowing that broader literature suggests ambiguity in influence (e.g. Rothaermel, Agung, and Jiang 2007; Barge-Gil 2010).

2.4. Openness and growth

Much research has been done with regard to impacts of openness, mainly on broader (open) innovation results. And often a positive influence has been observed (Powell, Koput, and Smith-Doerr 1996; Wikhamn, Wikhamn, and Styhre 2016; Hochleitner, Arbussà, and Coenders 2017), while in selected studies a trend of curve-linearity – as diminishing returns – was the outcome (e.g. Laursen and Salter 2006; Sampson 2007; Leiponen and Helfat 2010; Huang et al. 2015). We assume that such outcome will also hold true for growth of the firms, and in line with the above ambiguity, we phrase:

7a) Openness in knowledge relationships has a positive influence on firm growth in a linear relationship.

7b) Openness in knowledge relationships has a curvilinear influence on firm growth.

Figure 1 shows the research framework adopted in this study, indicating that we explore direct influence of firm antecedents and of various control factors on openness, as well as direct influence of openness on firm growth.

3. Data, measurement and modelling

3.1. Sample

We used an existing database derived from face-to-face interviews in 2006/7, including spin-off firms from Delft University of Technology in Delft (the Netherlands) and National Technical University of Norway in Trondheim (Norway), and we followed them until 2012. The economy in the region of Delft (Rotterdam) is relatively large, with diversified activities, including commercial and service (seaport-related) activity, and (petro)chemical and food industry, while the regional economy in

the case of Trondheim is relatively small and less diversified, with emphasis on agriculture, maritime services and industry related to oil/gas exploitation and wind energy.

The aim of the interviews was to depict knowledge relationships (openness), antecedents of this openness and growth among all spin-offs not older than 10 years. All firms that qualified (150) were approached which resulted in an overall response rate of 70% (105 firms). The interviews, using a semi-structured questionnaire, took 50–90 minutes. Almost all respondents were part of the original founding team and member of the management team. Using a longitudinal design, the same firms were investigated until 2012 concerning their growth, using e-mail communication or telephone.[1]

3.2. Measurement

We 'operationalised' openness as the level of diversity in partner types, regarding socio-economic position and location. To capture the first, we distinguished between large business, university, small business, government, family/friends, financial investor, lead customer, and to capture the second, we qualified the partner location as within the local/regional area or outside using a borderline of 60 minutes travel time by car, to distinguish new social circles from the familiar daily ones. Openness in knowledge relationships (partner diversity) (*Div*) is calculated for a core network of maximum five partners, as the product of socio-economic group diversity *(Hs)* and location diversity of partners (*EI*), as follows:

$$Div = Hs\left(1 + \frac{EI}{2}\right) \tag{1}$$

and

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

Hs is derived from the proportion of heterogeneous partners among all partners of a spin-off (Renzulli, Aldrich, and Moody 2000). Accordingly, a_k is the number of partners as part of a different socio-economic category, where *k* includes 8 categories (as indicated above). *N* is the total number of partners with whom a spin-off has a knowledge relation. Note that a partner could be assigned to only one partner type (main identity). A higher value indicates a higher level of socio-economic diversity (min: 0; max: 1). In addition, location diversity is calculated as:

$$EI = \frac{E_p - I_p}{E_p + I_p} \tag{3}$$

where E_p is the number of external, non-local, partners, and I_p is the number of local partners ($E_p + I_p = N$). Overall, the spin-offs in our sample face an average score on openness of 0.35; however, scores close to one also occur (Table 1).

Further, regarding organisational antecedents, the average founding team size is 2.3 fte, with a maximum of five. There is on average one domain of experience, but a minority (38%) has more domains with three at maximum, and there is on average 7.3 years of experience, however, with large variation. Taking the level of education, there is on average less than one PhD, with variation between zero and five. Further, most teams (nearly 66%) have members from the same educational discipline, while diversity in education happens at 34%. Innovation experience is on average 0.1 on a scale of −1.4–1.1, with quite some variation, and there is a modest participation in training (31%).

With regard to control variables, Trondheim is at a share of 42% and Delft at 58 per cent. Spin-offs active in science-based sectors are a minority (27%) while most (73%) are in other sectors. Firm size at time of the survey is on average 7.2 fte with a maximum of 51, and average age is 4.9 years with a maximum of 10. The outcomes of the previous variables have been transformed, using either logarithm or square root.

Table 1. Measurement and descriptive statistics.

Variables	
Control variables Openness model	
City-region: two categories (Trondheim = 1)	Trondheim: 42%; Delft: 58%
Sector: two categories (science-based = 1)	Science-based: 27%; Non-science-based: 73%
Market competition: two categories (many competitors = 1)	Many competitors: 56%; Few competitors: 44%
Firm size: full time equivalents (fte)	Avg.: 7.2; sd.: 6.9; min-max: 0.5–51
Firm age (2006/7)*:* years since foundation	Avg.: 4.9; sd.: 3.1; min-max: 0–10
Organisational antecedents (prestart)	
Founding team size: number of team members at foundation	Avg.: 2.3; sd.: 1.2; min-max: 1–5
Founders' experience domains: number of types of experience, e.g. research, management and other areas	Avg.: 1.1; sd.: 0.9; min-max: 0–3
Founders' experience duration: years of pre-start working experience (cumulative)	Avg.: 7.3; sd.: 13.4; min-max: 0–73
Founders' education level: number of PhDs	Avg.: 0.6; sd.: 0.9; min-max: 0–5
Founders' education diversity: two categories (multiple studies = 1)	Single technology (65.7%); Multiple studies (34.3%)
Antecedents (after start)	
Level of innovation experience: continuous variable (R&D expenditure, newness in innovation, patents) (Appendix 1)	Avg.: 0.1; sd.: 0.85; min-max: −1.4–1.1
Participation training: two categories (yes = 1)	Yes (31.4%); No (68.6%)
Dependent variable Openness model	
Openness: continuous variable, incl. socio-economic position and location of partners	Avg.: 0.35; sd.: 0.2; min-max: 0–0.9
Control variable Growth model	
Entrepreneurial orientation: three categories	Small plus local: 10%; Small plus international: 53%; Large plus international: 37%
Dependent variables Growth model	
Employment: four categories (rank)	Closed: 12%; negative and no growth: 39%; low/medium: 26%; strong growth: 23%
Turnover: four categories (rank)	Closed: 13%; negative and no growth: 51%; low/medium: 20%; strong growth: 16%

3.3. Estimation methods

Concerning openness, we start with linear multiple regression analysis, using the backward stepwise method. First, the full model is estimated, including all independent variables and next, variables are removed in such a way that the model power, R^2, and statistical significance of the model yield the best results. As preparation, multi-collinearity was checked (Table 2). A high correlation between firm size and firm age makes it crucial to select one, and firm size is taken because of the stronger models. With regard to the diagnostic tests, all tests satisfy the assumptions: no serious concerns regarding outliers, the residuals are normally distributed and homogeneous, and the tests for model specification errors produce satisfactory results (Appendix 2). In addition, endogeneity of the model is addressed and the test results indicate no reasons for concern (Appendix 3).

4. Openness: antecedents and outcomes

4.1. Influences on openness

The optimal regression model of openness is shown in Table 3. With regard to control factors, the city-region produces significant results, it shows that spin-offs in remotely located Trondheim tend to employ a larger openness in knowledge relationships, most probably with launching customers at large distances, e.g. in Bergen or Oslo. The next control factor, sector type, does not show significant influence on openness and this holds also true for perceived market competition. Finally, firm size at the survey, does show significant and positive influence on openness.

The power of the optimal model (0.53) indicates that the antecedent variables produce a relatively high level of explanation of openness in knowledge relationships in a linear model. The results will be discussed in more detail below, including curve-linear influences (Table 4), and testing of the hypotheses (Table 5).

Table 2. Correlation matrix ($n = 105$) a).

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	City region	1.00												
2	Firm age	−0.21*	1.00											
3	Firm size	−0.16	0.53*	1.00										
4	Sector	0.11	−0.21*	−0.28*	1.00									
5	Market competition	−0.11	0.20*	0.03	−0.14	1.00								
6	Founding team size	0.14	−0.35*	0.17	−0.06	−0.07	1.00							
7	Founders' experience domains	0.33*	0.01	−0.07	0.11	−0.05	0.06	1.00						
8	Founders' experience duration	0.14	0.13	−0.09	0.13	0.00	−0.14	0.63*	1.00					
9	Founders' education level	0.19	−0.09	−0.15	0.29*	−0.12	0.01	0.37*	0.39*	1.00				
10	Founders' education diversity	0.20*	−0.01	0.33*	0.07	−0.05	0.32*	0.06	−0.04	−0.00	1.00			
11	Participation in training	−0.04	−0.28*	−0.08	0.25*	0.05	0.19	−0.13	−0.00	0.07	−0.09	1.00		
12	Innovation experience	0.12	−0.37*	−0.14	0.38*	−0.40*	0.07	0.20*	0.15	0.28*	0.03	0.03	1.00	
13	Openness	0.16	0.15	0.52*	0.09	−0.03	−0.00	0.22*	0.11	0.09	0.37*	−0.00	0.17	1.00

a) Spearman correlation coefficients.
*$p < 0.05$.

Table 3. Stepwise linear regression of openness.

	Initial model (s.e.)	Optimal model (s.e.)
Control variables		
City region (Trondheim = 1)	0.33 (0.17)*	0.37 (0.16)**
Sector (science-based = 1)	0.30 (0.21)	0.31 (0.19)
Market competition (perceived)	0.10 (0.17)	–
Firm size (fte, at survey)	0.72 (0.11)***	0.81 (0.11)***
Organization antecedents (pre-start)		
Founding team size	−0.64 (0.24)***	−0.45 (0.22)**
Founders' experience domains	0.19 (0.10)**	0.20 (0.08)**
Founders' education level	0.01 (0.14)	–
Founders' education diversity	0.43 (0.18)**	0.30 (0.18)*
Antecedents (after start)		
Level of innovation experience	0.21 (0.11)*	0.21 (0.09)**
Participation in training	0.45 (0.36)	–
N	105	105
F	7.99***	15.35***
R^2	0.49	0.53
Root MSE	0.76	0.71

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table 4. Curve-linear model tests of antecedents' influence on openness (one-by-one).

	Openness beta-coefficient (s.e.)
(Inverted) U-shape	
Founding team size	−0.90 (0.68)
Founders' experience domains	−0.13 (0.10)
Founders' education level	0.10 (0.04)**
Level of innovation experience	−0.20 (0.19)
Cubic pattern	
Founding team size	−0.79 (0.86)
Founders' experience domains	0.13 (0.05)**
Founders' education level	0.03 (0.01)**
Level of innovation experience	0.18 (0.09)**

**$p < 0.05$.

Table 5. Summary of hypotheses testing a).

		Models
Firm antecedents	***Openness (linear)***	***Openness (curvilinear)***
H1a/b Founding team size	Rejected (−)	Rejected (not significant)
H2a/b Founders' education level	Rejected (not significant)	Supported (+) (also cubic pattern)
H3 Founders' education diversity	Supported (+)	Not applicable
H4a/b Founders' experience domains	Supported (+)	Supported (only cubic pattern)
H5a/b Level of innovation experience	Supported (+)	Supported (only cubic pattern)
H6 Participation in training	Rejected (not significant)	Not applicable
Firm openness	***Growth (linear)***	***Growth (curvilinear)***
H7a/b Openness (employment)	Supported (+)	Supported (−)
H7a/b Openness (turnover)	Rejected (not significant)	Supported (−)

a) in brackets: observed coefficient signs.

Four out of six antecedents in the initial model are found to be significant, including size of founding team. However, the last influence is negative which indicates that larger founding teams tend to create less openness, most probably because much knowledge is already present in the team or processes of 'social loafing' are taking place (Hypothesis 1a can be rejected). Further, education level is

not part of the optimal model (H2a can be rejected), while diverse education is found to have a positive influence on openness (H3 is supported). Also, founders' experience domains has a positive effect, indicating that experience in different domains tends to stimulate a larger openness (Hypothesis 4a is supported). Innovation experience is also part of the optimal model, indicating that a higher level experience causes openness to increase, specially, when spin-offs collaborate in diversified consortia, and discuss their research outcomes in conferences, etc. (H5a is supported). This trend is broadly in line with Drechsler and Natter (2012) and Xia (2013) with regard to the positive impact of internal R&D on the degree of openness and Riccobono, Bruccoleri, and Perrone (2015) on positive influence of firm R&D experience (through patents) on mode of external knowledge sourcing. However, the result contradicts Barge-Gil (2010), who argues that open innovators are less R&D intensive. Finally, participation in training is not part of the optimal model (H6 can be rejected).

As a next step, curvilinear relationships are explored for those influences for which we assume that higher values lead to a diminished openness, and in our study could be measured on a ratio scale. First the quadratic terms are inserted, in a one by one manner in an empty model, to explore inverted U-shaped patterns (Table 4). The coefficients, however, are found not to be significant except for education level, and this indicates – different from our expectations – a U-shaped pattern of openness, meaning a disproportionate increase of openness with increasing numbers of PhD's in the founding team.

Furthermore, not one but two 'turning points' may occur in the influence on building open networks – from increasing to decreasing openness and from decreasing to increasing openness – eventually in parallel with crossing critical junctures that requires new knowledge combinations (Vohora, Wright, and Lockett 2004). In line with this, we explore cubic terms based on the equation $y = ax^3$, and significant coefficients are observed for founders' education level, experience (domains), and innovation experience (Hypotheses 2b, 4b and 5b are supported). Overall, the positive coefficients are similar to the respective coefficients in the optimal linear model.

4.2. Openness influencing firm growth

We use employment and turnover data in a five-year period (between 2006 and 2011/12) following measurement of openness in 2006. Growth indices are constructed with different (ordinal) categories, including firms closing down and being integrated into larger firms after acquisition (Table 1). Accordingly, for employment growth 'negative growth' accounts for 35%, 'no growth' for 4%, 'low/medium growth' for 26%, and 'strong growth' for 23%. For turnover growth, these shares are 9%, 42%, 20%, and 16%.

A simplified ordinal regression model is estimated (Table 6). The results show that the coefficient of openness is positive and significant in the linear employment model, meaning that increase in openness tends to make employment growth increasing in a similar degree (Hypothesis 7a is

Table 6. A simplified ordinal regression analysis of employment and turnover growth

	Employment (s.e.)	Turnover (s.e.)
Openness	2.80 (1.17)**	−0.02 (1.23)
Openness (curvilinear)	−0.28 (0.13)**	−0.37 (0.15)**
Control variables		
Firm age	−0.29 (0.24)	−0.68 (0.25)***
Entrepreneurial orientation	0.53 (0.20)***	0.34 (0.20)*
N	105	104
LR chi^2	17.38***	19.83***
Log likelihood	−130.30	−126.49
Pseudo R^2	0.06	0.07

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

supported only for employment growth). At the same time, however, a negative sign of the coefficient in the quadratic relationship indicates an inverted U-shaped pattern, both for employment and turnover growth (Hypothesis 7b is supported). This preliminary result suggests that openness is important to growth, although not in a simple straightforward manner, as the positive influence tends to diminish and eventually becomes negative. This is in line with other studies' suggestions, albeit not for growth but for innovation (Laursen and Salter 2006; Leiponen and Helfat 2010; Huang et al. 2015) and albeit not for our broadly defined knowledge networks but knowledge collaboration (e.g. Sampson 2007). The rise of diminishing returns may indicate emerging managerial issues as a higher level of openness enables extensive (new) information entering the firm and interaction with more different partners. Accordingly, managing the partner relationships concerned may become a new struggle or challenge that needs to be dealt with. With regard to control factors, 'initial entrepreneurial orientation' tends to positively influence growth, meaning a consistent behaviour among spin-off firms in realising growth according to their early ambitions.

4.3. Case studies

The three case studies presented here, serve to illustrate contrast situations and trends in openness and antecedents as well as firm growth. Firm A started with one employee, operating in biotechnology with applications in bio-separation and bio analysis. In 2006, it spent 10% of turnover on R&D to finance its development stage, while at the same time providing consultancy work by two employees with similar technical education. A small diversity in experience and education tended to cause a limited openness, as the firm only connected with a government officer and university professors locally. The firm, ten years old in 2011, shrank to one full time employee with a stable turnover not exceeding 100,000 Euro.

Firm B (also 10 years in 2011) started with three employees using optical technology with application in lithography. In contrast to the previous firm, in 2006, it spent almost half of turnover on R&D and this resulted in many inventions protected by patents. This highly innovative firm benefited from high level education and diversity in education, including two team members with PhD (technical) and two other ones educated in management (human resources, and business). It connected with many different partners including senior executives of large firms, university professors and government officers within the country and abroad; this in order to gain very specialised knowledge. The firm had over 150 employees in 2011 and raised a relatively large turnover of more than 500,000 Euro while in the stage of market introduction through a launching customer. In contrast, firm C, involved in innovative medical equipment, was constrained by modest education (no PhD) and lack of business experience, but developed a large openness. It almost 'collapsed' in managing different knowledge flows simultaneously (investment capital, global exports and subcontracting its manufacturing) and was forced to be sold to a larger firm aged eight years.

5. Discussion

The aim of the study was to explore under which influences university spin-offs shape openness in early knowledge relationships, and to explore the impact of openness on later firm growth. The empirical contribution of this study is to the debate concerning the influence of antecedents, as a set of cognitive resources and experiences, on shaping of openness in knowledge networks. Firstly, the results confirmed the influence of various founding team antecedents on openness, although not always in a positive and linear relationship. One antecedent acted as a *negative* influence, namely, size of the founding team, most probably because the knowledge need becomes served internally after some time. Three other antecedents acted as *positive* influences on openness, namely, founders' experience domains, diversity in founders' education and level of innovation experience.

Secondly, our search for non-linear influences on openness, found no *inverted* U-shape relationships. Instead, one U-shaped relation was found, namely, for education level, whereas three cubic trends were identified connected to founders experience, education level and innovation experience. The last trends are most probably connected to two turning points (critical junctures) where knowledge network requirements are being redefined (Hite and Hesterly 2001; Vohora, Wright, and Lockett 2004), indicating complexity in the matter. Among the antecedents one clear positive 'driver' of openness was identified, namely level of innovation experience, which complies with Drechsler and Natter (2012), Xia (2013) and Riccobono, Bruccoleri, and Perrone (2015) but not with Barge-Gil (2010). In addition, PhD level seemed to be a key enabler of openness, because of increasing returns, reflecting a similar trend. Overall, antecedents representing diversity and high-level innovation/science tend to increase openness in knowledge relationships, and this is more evident among spin-offs from universities active in consortia and leading conferences, compared to other young ventures.

A third contribution is drawn from case studies. Our results indicate the co-existence of at least two types of spin-offs, from the viewpoint of 'liability of newness' (Stinchcombe 1965) and dynamic capabilities. One with weak antecedents, small openness (partner diversity) and limited growth, and one with stronger antecedents, larger openness, and subsequent larger growth, although positive influence on growth may vanish in a management struggle if capabilities have remained poor. In this sense, our results contribute to a more nuanced view on 'liability' of young high-tech firms.

With regard to practice and management in academic entrepreneurship, it can be advised – if openness and growth are the aim – to take the early innovation level as well as size and composition of the founding team into account, the last focussing on varied education, including PhD level, and varied experience. Also, to prevent a struggle of spin-off's management with too strong openness, a delicate balance needs to be found between openness and management capability, eventually by strengthening the management team.

This study also has some limitations. Firstly, the generalizability of the results is somewhat limited, namely, confined to technical universities in coastal Northwest Europe with strong presence of maritime (energy) and coastal (seaport) activities at universities, as well as the specific profile of Norway and the Netherlands as innovation 'follower' at the time (Pro-Inno Europe 2010). Also, regarding the larger group of young high-tech ventures, we foresee a somewhat limited generalizability. We expect university spin-offs to be more open in knowledge relationships than their counterparts derived from a stronger innovation performance and higher education level (PhD), and we also foresee the rise of more management issues because young university spin-offs typically lack managerial resources (van Geenhuizen and Soetanto 2009). Secondly, due to small sample size, our openness model was explored using a limited number of factors. Increasing parameters could further improve the model, for example, addressing professionalization of founding teams and narrowly defined industrial sectors a firm operates in. And thirdly, mainly cross-sectional and short-term longitudinal data on growth were used. Future research could use longer timelines to enable insights into the temporal dimension of openness and of negative and non-linear trends (Rodriguez-Gulias, Rodeuro-Pazos, and Fernández-López 2017), with attention to change in development stages (Vohora, Wright, and Lockett 2004), attraction of professional investment capital (Colombo and Grilli 2010; Drechsler and Natter 2012) and organisational forms of knowledge partnership, e.g. knowledge gaining or comprehensive collaboration (e.g. Sampson 2007). Those types of research would be valuable, because openness was found to make a difference in growth of spin-off firms, causing a compelling need for incubator (university) managers to be cautious in providing support aimed at an increased openness. Thus, a deeper clarification and better underpinning of support policies are needed, given the complexity and struggle addressed in this study.

Note

1. Excluding spin-offs that were closed down within the study periods, could be a source of bias. However, mortality rates among university spin-off firms seemed relatively low (Mustar, Wright, and Clarysse 2008). Experts in Delft indicated an 85% survival rate (personal communication).

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1

Variables in the factor analysis used to calculate the innovation experience score, are below.

R&D expenditure: percentage of turnover (last three years)	Avg.: 39.8; sd.: 23.1; min-max: 0–100
Newness in innovation: three levels of innovation type (breakthrough and/or new to the sector)	High: 46%; Medium: 29%; Low: 25%
Patents: two categories (patented = 1)	Patented: 44%; Non patented: 56%

Three methods are used: principle factor, principle-component factor and maximum-likelihood factor. The results are consistent and robust.

Appendix 2

Linear regression diagnostics tests of openness.

Diagnostic test	Outcome
Unusual data (bias) using residuals, Cook's D and DFBETA	Checked
Normality of residuals tests	(1)interquartile:1 outlier (2)Shapiro-Wilk: z:−1.838; *p*-value:0.97
Heteroscedasticity of residual (1) White and (2) Breusch-Pagan test	(1)chi^2:32.20; *p*-value:0.46 (2)chi^2:1.61; *p*-value:0.20
Multicollinearity	Mean VIF:1.17
Model specification error (Ovtest)	F:2.47; *p*-value:0.07

Appendix 3

The variable innovation experience is a candidate for being endogenous, as level of innovation experience may follow from openness. Being more open could lead to more experience in innovation. Innovation experience could be expressed better by other exogenous variables, like sector (science-based or not). Endogeneity of this variable was checked in each model, calculating Durbin and Wu-Hausman statistics. Overall, there are no indications of endogeneity.

Endogeneity test.

	Instrument Variable	Durbin	Wu-Hausman
Openness	Sector	Chi $^2(1) = 0.03$; $p = 0.86$	$F(1,94) = 0.03$; $p = 0.87$