Open innovation: how academic spin-off firms match incoming knowledge with knowledge gaps on critical resources

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Abstract— Many academic spin-off firms experience resource deficiencies that slow down their growth. In this paper, we investigate the critical resources that are missing and knowledge retrieved from networks to solve or prevent missing resources, to better understand the causes of slow growth. In a sample of 105 spin-offs from Norway and the Netherlands, it is found that spin-off firms most frequently lack three types of resources: marketing skills, management skills and (knowledge on) financial capital. High severity in terms of duration is observed for marketing and managerial resources compared to financial capital. We also observe a trend that knowledge retrieving through the network happens in a somewhat unstructured and chaotic manner. However, the matching between lack of financial resources and retrieving knowledge on these resources tends to be effective, as is witnessed by a positive influence on employment growth of the spin-off firms.

Keywords—resource deficiencies; knowledge networks; matching; open innovation

I. INTRODUCTION

Many academic spin-off firms experience a short in resources that slows their growth [1],[2],[3]. A slow growth contradicts the high policy expectations about academic spin-off firms: they commercialize knowledge developed at universities, increase high-tech employment and improve the business ecology in the region, while contributing to a wider diffusion of new and often sustainable technology in society. It is therefore important to increase insights into the background and context of slow growth among academic spin-off firms. This research does so by analysing the issue of matching of gaining of external knowledge with resources that are missing in the context of open innovation and open knowledge networks.

Innovation and growth have increasingly become the result of interactive processes between a wide range of parties, like suppliers, sub-contractors, competitors, customers, and universities [4], [5]. This change has been conceptualized as open innovation, 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 [4]. Aside from the 'outside-in' and 'inside-out element', innovation may benefit from coupled processes or co-creation with complementary partners [6]. Given their lack of resources and slow growth, academic spin-off firms are in a situation that calls for the adoption of some modes of open innovation and open knowledge networks. The entrepreneurs are often graduates form university or university staff members who face a lack of market understanding and marketing skills, management skills and (knowledge about gaining) financial capital [3],[7]. What seems particularly important in this context is that entrepreneurs recognize valuable resources, specifically knowledge, they are missing in a timely fashion, and establish networks that match these missing resources accordingly.

This research aims to fill the following knowledge gaps in the literature. First, much research has been devoted to open innovation in the recent past, however, most of it is about open innovation in large firms and very little about small firms [2],[5],[8],[9],[10]. Thus, the current research focuses on small firms, namely academic spin-off firms. Second, most of the research on open innovation has been done in a qualitative way while quantitative research methods haven't been applied so often. As suggested by [11], the current research creates a quantitative look. Moreover, the third gap the current research tries to fill is understanding the types of knowledge domains that are addressed in knowledge relationships of firms and how firms match their incoming flow of knowledge with critical resource deficiencies they are facing. Since there has been no research on this specific subject, according to our experience, the current research presents a new approach to deal with resource deficiencies and creates quantitative insights into how academic spin-off firms adapt their incoming knowledge flows to the resources they are missing. The focus in this approach is on the type of match in knowledge flows, while the relation between the match and growth of the firm is explored in a preliminary way.

The match is conceived in the current research as the

reaction of firms to resource deficiencies in terms of response and severity. A good match would mean that firms are solving problems before they emerge, and is therefore defined as pre-emptively acquiring external knowledge. A bad match on the other hand, would mean that a firm is not responsive to resource deficiencies in terms of attracting external knowledge about the specific resources involved. A bad match is connected to a passive attitude to resource deficiencies in terms of acquiring knowledge from networks. Firms facing the worst match are those experiencing severe resource deficiencies, but are neglecting them in terms of attracting knowledge to solve them. In this case, they are not involved in meetings like with business consultants, technology specialists, informal investors, launching customers, etc. to discuss and reduce their problems.

In responding to the knowledge gaps mentioned above, this study addresses the following research questions: What resources are missing, and can be seen as structurally missing? How does the knowledge retrieved from the networks match with these resources and what is the influence of this match on growth?

A sample of 105 academic spin-offs is used in the analysis and the results unfold as follows. In section II, theoretical views are discussed. Data, operationalization of variables and description of the sample of spin-off firms are addressed in section III and IV. This is followed by a discussion of the results on responsiveness and severity in the match in the last section.

II. THEORETICAL VIEWS

Young and small academic spin-off firms are highly dependent on external resources which they may gain through networks with the university, colleagues in incubators, large firms, consultancies, intermediaries, etc.[13], [14],[15],[16].

In this framework, firms can be conceptualized as a bundle of tangible and intangible resources, including a firm's management skills, its organizational processes and routines and the information and knowledge it controls, which can be used to select and implement strategies [17]. The availability and diversification of resources [18] are perceived as a source of competitive advantage and superior performance. Specific for young spin-off firms is the situation of facing various critical junctures in the course of their development cycle, these critical junctures arise from a conflict between the existing (level and type of) resources, capabilities and social capital, and those required to reach the next development phase [12]. In many cases, young spin-offs fail because they have inadequate resources compared to what they need in that specific phase in their life line [12],[19], which can be prevented by them by increasing internal resources and capabilities through acquiring new staff and improving existing staff through training [20],[21], and by establishing

relationships to gain access to external resources and the concomitant knowledge about these resources [14],[15]. The ability of a firm to spot the changes in the business environment in which it operates and to recognize the needs at each specific phase in its life line, and reconfigure its internal and external resources to address change accordingly, is a critical ability and is called a firm's dynamic capability [22].

In this vein, a firm's ability in matching its missing resources with the knowledge and information gained through networks, is important and constitutes a part of a firm's dynamic capability [23]. Thus, our approach to investigate the match has a clear focus on a specific part of the dynamic capability of academic spin-off firms while focusing on the ability of these firms to utilize their knowledge networks to respond to missing internal resources.

There is quite some differentiation among academic spin-offs in internal resources and capabilities [24],[25]. They start with different capabilities and resources - as evidenced in the founding teams. For example, not all possess the same human capital resources or networking capabilities. Some firms have more time available to manage larger networks, while others possess more experience and better judgement to identify and connect with most beneficial partners. Accordingly, better developed networking capabilities among founders and employees may cause academic spin-off firms to obtain a competitive advantage or even a sustained competitive advantage over other firms [17].

The goal of this research is to understand how firms match the knowledge retrieving from their network with the resource deficiencies they are facing. Different matches will be established based on the incoming knowledge firms obtain and the resources they lack.

III. DATA AND METHODS

A. Data

The database used in this study has been created through personal, in-depth, interviews with principal managers of 105 firms in 2006/7. All firms in the database are spin-offs from two technical universities in Europe: TU Delft (Delft, the Netherlands) and NTNU (Trondheim, Norway). The Netherlands and Norway share a similar, rather risk-avoiding culture in entrepreneurship and are both qualified as innovation followers [26], while both countries are facing relatively small domestic markets calling for stretching knowledge relations, among others, in foreign markets. The database has been constructed as follows: first the target population of spin-offs was identified using the following conditions: dealing with commercialization of knowledge created at the universities, survived to 2006/7 with an age not older than 10 years, and at least received one type of support from the incubation organization/university. Next, these spin-

offs were contacted to invite for the interview and this has led to a response rate of 70 per cent.

The sample of spin-offs contains manufacturing and service activity. The manufacturing includes machinery, chemicals, computer and electronic products, while the services mainly cover information and telecommunication, and professional and technical activity [27]. The new technologies involved include new material and nanotechnology, sensor technology, control systems, biotechnology and mechatronics. On average, the spin-off firms in the sample are 5 years old in 2006, in a range from 1 to 10 years, and they employ almost 7.5 full time equivalents (fte). Around 40 per cent of the sample is located in Trondheim and 60 per cent in Delft (See Appendix 1).

B. Measurement of Variables

Five types of matches are identified and measured. These are the so-called 'overall matches' which are company-wide and three matches per separate resource ('sub-matches'), namely marketing skills, management skills, and financial resources. As a consequence, for the three separate matches, it is possible for a firm to have a poor match for one but a strong match for another, as the three matches per resource are independent of each other. However, the company-wide match is strongly correlated to each separate match. In more detail, the matches are combinations of three separate types of resource deficiency and contents of knowledge which were obtained in meetings with important partners, like casual meetings (friends, colleagues), consultancy meetings, and business meetings (large firms, financial investors, etc.). We distinguish between three 'sub-matches':

- Marketing match between:
   – Deficiency concerning marketing knowledge and skills
   – Content of knowledge: advice on (access to) new markets/customers
- Management match between:
   – Deficiency concerning managerial capacity (too many tasks to handle)
   – Content of knowledge: advice on modes of managing the firm
- Financial capital match
   – Deficiency concerning financial capital (including R&D investment)
   – Content of knowledge: advice on (access to) various types of finance, e.g. loan, venture capital, business angels, etc.

The current study is retrospective in the sense that the spin-off firms were asked to make an inventory of their major missing resources in the years prior to the interview and the main content of meetings with important partners. As memory bias could have played a role, the years mentioned and the character of missing resources were consciously checked during the interviews.

We count the number of lacking resources before 2006/7 and the number of different contents in the attracted knowledge. In order to ensure comparison of the results, the values are normalised.

We measure the matches as follows:
- *Response match*, which indicates how the firms respond to all three missing resources, in terms of absence/presence of a missing resource and absence/presence of specific knowledge retrieving from the network. The diversity of a firm's resource deficiencies relative to the diversity of the incoming knowledge is calculated using Harrison's method [18].
- *Severity match*, which indicates the match between severity of the missing resource and frequency of meetings in which the relevant knowledge is the core subject of discussion. In this case, resource deficiency of a firm is compared to firms of the same age; this serves to remove the bias caused by age, as older firms face a higher chance of having experienced resource deficiencies but also have gained more experience and skills in establishing efficient knowledge relationships. The severity match is calculated for the three missing resources separately.

The response match indicates how diverse the number of incoming knowledge contents are, and how diverse the resources the firm lacks are. The indicator is built to identify at least three types of firms in terms of responsiveness: (1) pre-emptive, it faces no resource deficiencies, but participates in several meetings, (2) reactive, it faces both resource deficiencies and participates in meetings, and (3) passive, it faces resource deficiencies without participating in meetings. Due to a lack of data about when the knowledge exchange exactly took place, the time-dimension cannot be included in the current analysis and the response match remains relatively broad.

The response match is calculated on the basis of the diversity of a firm's incoming knowledge flows relative to the diversity of the resources it lacks (for details on the steps and formula used, see [28]). The results of the match range from -0.75 to +0.75, where the first means a firm is non-responsive to resource deficiencies, and the last means a firm is pre-emptively using its network to counter the rise of future resource deficiencies.

The severity match measures how the frequency of contacts in meetings about a certain resource, indicating efforts to solve/prevent problems, relates to the severity of the resource deficiency. A ranking calculates the match per resource, three sub-matches are involved (one for marketing skills, management skills/time, and financial capital). Because the number of years a firm can lack a resource is among others dependent on its age (a firm cannot experience a problem for longer than its own age) the match needs to account for

the differences in age. Therefore, firms are compared to the firms of the same age (for steps and details of formula, see [28]).

IV. RESULTS

A. Missing Resources

The results show that marketing skills, managerial skills, and financial capital are the three resources which academic spin-off firms lack most often (Table 1). Marketing skills are missing at a level of 53.3 per cent, this is followed by lack of financial capital at 46.7 per cent and managerial skills at 34.3 per cent. This picture is also found in a previous study only on the Netherlands [2] and a more recent study including Finland, Poland and Portugal aside from the Netherlands [29]. This research therefore focuses on these three resources.

TABLE 1. SHARE OF FIRMS MISSING VARIOUS TYPES OF RESOURCES (N=105)

Type of resource	Share of firms (%)
Marketing skills	53.3
Lack of (access) to financial capital	46.7
Managerial skills and time	34.3
Research facilities	10.5
Cooperation opportunities	5.7
Technological skills	2.9

Table 2 shows how severe the missing of resources has been in terms of duration, i.e. in average number of years. Since the analysis only includes firms which were missing the resource, the number of observations per resource varies. On average, marketing skills were missing for three years, with managerial skills/time very close at an average number of years of 2.8. Missing financial capital is shortest, a good two years. A shorter duration of lack of financial capital can be explained by the situation that missing this resource is easier to be noticed and recognised, and by a stronger drive to solve it. In order to determine how many spin-offs have experienced resources as 'structurally missing', resources are taken into account which have been missed for longer than the average duration (as shown in Table 2). It appears that these are small groups in the sample, not exceeding a share of 20 per cent.

TABLE 2. SEVERITY OF MISSING RESOURCES

Type of resource	Severity (duration in years)*	'Structurally' missing firms, abs. and share	'Structurally' missing firms as share of firms missing the resource
Marketing skills (56 firms)	3.0	18 (17.1%)	32.1%
Managerial skills/time (36 firms)	2.8	17 (16.2%)	47.2%
Financial capital (49 firms)	2.1	13 (12.4%)	26.5 %

* the results of the Kruskal-Wallis test show (p<0.01): that the difference in average severity between lack of financial capital, and marketing is significant, and that the average severity between lack of financial capital

and management is significant.

However, if we take these as part of only the spin-offs that have suffered from the missing of the resource, different trends emerge, with managerial resources as the most persistent missing resource, at 47.2 per cent, and financial capital as the least persistent resource, at 26.5 per cent.

In order to get insight into the effect of age on lacking resources, Table 3 shows the frequency of firms lacking resources sorted by year of occurrence. It is clear that the amount of firms lacking resources decreases when firms grow older. This is in line with expectations since older firms have more experience in gathering resources. It can also be assumed that firms who lack a lot of resources go bankrupt, which causes a sort of natural selection, leaving firms who do not lack resources. Such processes have not taken place at a significant scale as death rates were very low and the profile of firms that could not survive is not significantly different from the ones that survive [2]. For reasons already indicated above, lack of financial resources is least persistent over the life time of spin-offs, as it has largely disappeared at age five. And again, management skills/time tends to be the most persistent missing resource, still present at more than 5 per cent at the age of seven to the age of ten.

B. Response Match

The number of firms that obtain knowledge about marketing skills (91 firms) and management skills (77 firms) from their networks is about twice the number of firms lacking these resources (56 firms and 36 firms respectively). This seems not true for financial capital, where this ratio is just above one. Comparing the number of meetings per type of content, no statistical differences can be observed. Generally speaking the firms tended to put more effort into obtaining knowledge about marketing and management skills than about financial capital.

In the remaining section we discuss the frequencies of the responsiveness match (Table 4). We notice that there are no firms with a match in-between -0.5 and -0.25, and 0.25 and 0.5. The absence of these values is due to the limited number of three categories, and the way diversity is calculated [28]. The results (Table 4) indicate 12 extreme cases, one spin-off who is non-responsive at all to a lack of resources in terms of obtaining knowledge and 11 spin-offs who are pre-emptively using networks (meetings) to obtain knowledge about one of the three resources. The other 93 spin-offs have matching values ranging from -0.25 to 0.25. A value of zero means there is no difference in the diversity of incoming information and missing resources. On the positive side, one third (66.7 per cent) of all firms in the sample qualify strong, very strong responding or pre-emptive, while on the negative side, 20 per cent qualify as non-responding, very poor and poor in responding. This pattern indicates a quite high level of good matching, but also that there is a relatively small group of spin-offs that call for attention because of a bad match.

TABLE 3. FREQUENCY OF LACKING RESOURCES BY AGE

Age of the firm	1	2	3	4	5	6	7	8	9	10	11
Number of firms which are at least the age indicated (column)	105	104	88	74	69	61	47	29	26	18	14
Number of firms lacking marketing skills at age (column)	44	36	24	14	6	2	2	1	0	0	0
% of firms lacking marketing skills	42%	35%	27%	19%	9%	3%	4%	4%	0%	0%	0%
Number of firms lacking management skills at age (column)	26	19	15	6	2	2	3	2	2	1	0
% of firms lacking management skills	25%	18%	17%	8%	3%	3%	6%	7%	8%	6%	0%
Number of firms lacking financial capital at age (column)	32	21	14	7	1	1	1	1	1	0	0
% of firms lacking financial capital	30%	20%	16%	9%	1%	2%	2%	4%	4%	0%	0%

TABLE 4. FREQUENCY OF RESPONSE MATCH SCORES (N=105)
(ABS. NUMBER OF FIRMS)

Matching scores	≥-0.25 < -0.125	≥-0.125 < 0	0	> 0 ≤0.125	> 0.125 ≤0.25	≥0.5 ≤0.75
Degree of match	very poor	poor	average	strong	very strong	pre-emptive
Firms	9 *	12	14	23	36	11

*One firm is non-responsive

C. Severity Match

The severity match deals with the severity of the missing resource in terms of duration (years) and the amount of effort undertaken to solve the problem (frequency of contacts). The second difference is that the severity match does show whether a firm is pre-emptive or non-responsive concerning a specific missing resource. When analysing the severity match values (Table 5) it becomes clear that the distribution of ranking values is skewed: there are more firms retrieving external knowledge than there are firms experiencing resource deficiencies. The trends in the table point to the following pattern: a relatively large number of spin-offs gain the score 'average', but also 'good' and 'very good', but it seems that the positive trend is somewhat weaker in these particular matches compared to the responsiveness match, with a slight negative trend for marketing resources, witness a relatively large number of firms in the category average to poor.

Remarkably, the trends found above for the persistence of missing resources, namely, managerial resources as most persistent, is not reflected in the severity match as serious mismatches. This may indicate that despite large efforts to gain additional managerial knowledge/skills, solving missing management skills remains difficult.

TABLE 5. FREQUENCY OF SEVERITY MATCH SCORES PER RESOURCE (ABS. NUMBER OF FIRMS)

Matching scores	≥-1 <-0.7	≥-0.7 < -0.4	≥-0.4 < -0.1	≥-0.1 ≤0.1	> 0.1 ≤0.4	>0.4 ≤0.7	>0.7 ≤1
Degree of match	very poor	poor	average to poor	average	average to good	good	very good
Firms and marketing	4	10	20	25	16	13	17
Firms and management	8	7	8	27	21	21	13
Firms and financial capital	7	9	12	44	11	8	14

D. Match and Firm Growth

In a final step, we explore the influence of the three severity matches on employment growth of the spin-off firms, in the five years following the interview. We use a backward stepwise procedure in multiple regression analysis, meaning that we present an optimal model containing those independent variables that produce the best results in terms of model fit. We explore the influence of the severity matches concerning marketing, management and financial capital in Model 1, Model 2 and Model 3 respectively (Table 6). The type of analysis is Ordinary Least Square, and the common statistical checks indicate that there are no particular concerns.

It appears that only the match concerning financial capital has a positive and significant influence on employment growth given the model structure. This result indicates that a strong effort in gaining knowledge about financial capital solutions is an effective response, and this matches with the relatively short duration of this particular shortage as observed earlier in this paper.

Note that all models show a trend of negative influence of knowledge retrieving in general. This result may be caused by too strong efforts (most of the firms are on the positive side, namely, strong to pre-emptive), in other words, a less structured and slightly chaotic knowledge gathering. Apparently, knowledge gathering at the appropriate degree is a dynamic capability that needs to be learned by young firms.

TABLE 6. REGRESSION ANALYSIS OF EMPLOYMENT GROWTH (OLS)

	Model 1	Model 2	Model 3
Age of firm	0.039 (0.025)	-	0.046 (0.025)*
Location (Delft =1)	0.305 (0.152)**	0.395 (0.148)***	0.287 (0.150)*
Overall knowledge attraction	-0.542 (0.261)**	-0.563 (0.260)**	-0.537 (0.257)**
Marketing match	-0.083 (0.168)		-
Management match	-	-0.257 (0.173)	-
Financial match	-	-	0.304 (0.175)*
Nr. of firms	105	105	105
F	4.15***	5.37***	4.96 ***
R^2	0.14	0.14	0.17
Adjusted R^2	0.11	0.11	0.13

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

V. DISCUSSION AND CONCLUSIONS

Many academic spin-off firms experience resource deficiencies that may slow down their growth, while there are high expectations about their performance among policymakers. The aim of the paper was therefore, to gain more insight into the causes of slow growth, with particular attention to critical resources that are missing and knowledge retrieved from networks to solve or prevent missing resources. Accordingly, this study has addressed the following questions: What resources are missing, and can be seen as structurally missing? How does the knowledge retrieved from the networks match with the resources that are missing? We used a sample of 105 spin-offs from Norway and the Netherlands to answer these questions.

A trend was found that spin-off firms most frequently lack 3 resources: marketing skills at 53 per cent of all spin-offs in the sample, financial capital, at 46 per cent, and management skill/time, at 34 per cent. With regard to the severity of the lack of resources in terms duration, marketing (average of three years) and managerial resources (average of 2.8 years) tended to be missing for a significantly longer time than financial capital (average of 2 years).

According to the response match, two-third of the spin-offs qualified as strong, very strong responsive or pre-emptive while on the negative side, only 20 per cent qualified as non-responsive, very poor and poor. This pattern indicated a quite positive pattern of matching. The severity match was different by focusing on duration of missing skills and efforts in solving them, with separate scores for the three missing resources, altogether showing somewhat less positive trends. Further, the missing resource that calls for serious attention in incubator policy, is management skills because it is found to be somewhat difficult to solve despite relatively strong efforts of knowledge exchange. In solving problems of managerial skills, appointment of experienced staff seems more appropriate but also more difficult to realize by small firms without sufficient turnover.

With regard to growth, contrary to marketing and management, a proper match concerning financial capital was found to positively influence employment growth of the spin-off firms. A strong effort in gaining knowledge about financial capital solutions tended to be an effective response, and this matches with the relatively short duration of this particular shortage faced by the firms.

Due to the lack of data about the precise time of the knowledge exchange (meetings) it was impossible to include the time dimension in the match, other than 'the past years since establishment'. Hence the suggestion for further research to get information about the time of knowledge exchange. Further research could also be undertaken into spin-offs that are facing average and negative matches and how these matches relate to their growth pattern.

Both countries in the study, the Netherlands and Norway, share a somewhat risk-avoiding entrepreneurial culture in a small and open national economy, and specialize in new technology in seashore activities, mainly transport and energy, which indicates that the results may have implications for technical universities in a selected number of similar countries, such as Denmark, Sweden and northern parts of the United Kingdom.

APPENDIX 1 - TABLE 7. LIST OF VARIABLES

Variable name	Measurement	Descriptive statistics
Employment growth	Continuous variable as growth between start and 2010 through: (Size2010-Size at start)* 1/firm age 2010) in fte	Avg.:1.20; S.d.: 2.57 Min-Max:-1-16.3
Firm size (2006)	Continuous variable as number of full time equivalent	Avg.:7.2; S.d.:6.9; Min-Max:0.5-51
Firm age (2006)	Continuous variable as number of years since firm foundation in 2006	Avg.:4.9; S.d.:3.1; Min-Max:0-10
Industry type	In two categories	Science-based:27% Market-based:73%
Location	In two categories	Norway: 41% The Netherlands:59%
Overall knowledge attraction	Continuous variable as (number of incoming information) – (number of contents of information)	Avg.:0.71; S.d.:0.08; Min-Max:0-1
Response match	Continuous variable as $(1-\sum p_{information}^2)*$ - $(1-\sum p_{resources}^2)**$	Avg.:0.12; S.d.:0.22; Min-Max:-0.66-0.75
Severity match -Marketing -Management -Financial	Continuous variable as (meetings rank) - (lack of resource rank)*	-Marketing: Avg.:0.10; S.d.:0.49; Min-Max:-1,1 -Management: Avg.:0.18; S.d.:0.49; Min-Max:-1,1 -Financial: Avg.:0.05; S.d.:0.49; Min-Max:-1,1

* $p_{information}$ is the specific weight of a certain information flow, based upon the number of meetings, compared to all analysed information flows. $p_{information}$ is calculated for marketing, management, and financial capital information flows. The match is calculated using Harrison's method of diversity for categories for both the diversity of incoming information, and missing resources [18].

** $p_{resources}$ is the weight a certain resource deficiency has, based upon the number of years the resource was lacked, compared to all analysed resource deficiencies. $p_{resources}$ is calculated for marketing, management, or investment capital deficiencies.

*** the lack of resource rank, and meetings rank are both calculated per resource resulting in three sub matches. The rank is a percentage rank compared to the other firms of the same age, with a value of 0 (0% of the firms have less resource deficiencies or meetings) to 1 (100% of the firms have less resource deficiencies or meetings)

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