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SMALL RESPONSIBLE INNOVATORS AND OPEN INNOVATION TOWARDS SUSTAINABILITY: NETWORK CONDITIONS

Marina van Geenhuizen and Qing Ye

Abstract. Open innovation is key for innovators responding to major problems in the world, including energy, healthcare, water and the environment, and bringing transitions in socio-technical systems near. This paper has a focus on university spin-off companies as a channel of market introduction of new technology and responsible innovation. Although rich in technological knowledge, these companies suffer from lack of other resources, in particular, time, management experience and investment capital, reason why they need to limit their efforts in active participation in open innovation networks. The paper starts with a conceptual reflection on responsible innovation and open innovation practices in the frame of transitions towards higher sustainability levels. Responsible innovation can be seen as a transparent, interactive, process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation and its marketable products. Being engaged in responsible research and innovation means a relatively intense participation in the complex networks concerned.

The empirical analysis draws on 105 university spin-off companies and demonstrates that almost 60% of the companies are engaged in responsible innovation, with medical care/cure, sustainable energy, sustainable mobility, and waste treatment/recycling as the largest sectors, and that a good 40% are not involved in responsible innovation. Derived from regression analysis, the results indicate that responsible innovation is one of the drivers of open innovation in terms of size of the knowledge pool (themes) and diversity of this pool (different partners). However, diversity in the knowledge pool tends to influence growth of the companies negatively. Accordingly, it seems that the limited resources of university spin-off companies require ‘selectivity’ in choosing partners as a key condition for participation in networks (platforms) aimed at socio-technical systems’ change. This means to connect with merely one large companies as a launching customer and with a prominent investor, each on their turn being connected with a large diversity of network partners. At the same time, the need for selectivity tends to bring university spin-off companies in peripheral regions in a disadvantageous position compared to their counterparts in metropolitan areas, given the need for frequent interaction and a small chance to find the best matching partner(s) within the region. The paper concludes with implications of the findings and future research avenues.

Keywords: responsible innovation, open innovation networks, university spin-off companies, selectivity, socio-technical systems, transitions, spatial conditions.

JEL codes: D8, L2, O3, Q5.

1. Introduction: Responsible innovation, open innovation and socio-technical systems

There is an increasing insight that innovative entrepreneurship can play a major role in enhancing changes in socio-technical systems towards higher levels of sustainability, in other words in responding to the world's major challenges concerning food, water, environment, energy and health . Innovative entrepreneurs perceive new opportunities using existing or new, disruptive, technology and create new markets in interaction with important players in the socio-technical system (e.g., Linton and Walsh, 2008; Thierny and Walsh, 2008). That sustainability can work as a driver of entrepreneurial innovation is not entirely new. Since the late 1990s, various studies were published that emphasized a higher level of complexity if innovation is arising from sustainability aims, mainly caused by a higher complexity of the learning and learning networks (e.g., Roome, 2001; Hall and Vredenburg, 2003; Sweet et al., 2003). These networks have to include a wider variety of partners, like public policy makers, pressure groups, and customer groups aside from the conventional ones, calling for additional skills and competences of companies, in order to affect the socio-technical system at hand.

More recently a renewed interest has arisen derived from new pathways highlighted by the World Business Council for Sustainable Development in 2010. However, the emphasis to gear the innovation process to societal needs and desirable outcomes today is much stronger than in previous times, particularly in many high-level policy and strategy EU documents, such as the EU Innovation 2020 strategy to create smart growth and the Horizon 2020 program that defines Societal Challenges as one of the main priorities. The Millennium Goals have done the same, and the Lund Declaration (2009) underlines the importance of addressing ethical questions in research and development.

Concepts that have increased in popularity in this framework are responsible entrepreneurship and responsible research and innovation. Responsible research and innovation can be described as a transparent, interactive, process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation and its marketable products (von

Schomberg, 2012). This definition is clearly process-oriented emphasizing the interaction between entrepreneurs and science and society (see, also, van den Hoven et al., 2012; Owen et al., 2012), particularly between entrepreneurs and the system context. A policy supporting this development enables to avoid innovation that turns out to be contested, to attend fields concerning societal needs that have been unattended to date, and to continue successful innovation that have already been recognized, like green technologies (van den Hoven et al., 2013).

Responsible innovation cannot go without open innovation, and contributions to changes in socio-technical systems can never be brought about without such openness, reason why the focus in this paper is on this paramount process characteristic and its driving factors, i.e., open innovation. Learning is increasingly concerned with open innovation connecting the company with stakeholders in society, customer groups, public authorities, suppliers, competitors, universities, etc. (Chesbrough, 2003; Chesbrough et al., 2006). Understanding the market and application needs of customers, as well as increasing legitimacy by attracting prominent knowledge collaboration partners and prominent capital investors seem vital ingredients of the networks if sustainability aims need to be reached. However, research on the interrelationships between open innovation, legitimacy and the socio-technical system have remained scarce and deserve more attention (Davidsson, 2004; Dean and McMullen, 2007; Janssen and Moors, 2013). Also, differences in open innovation and underlying causes have rarely been revealed, except for Chesbrough and Crowther (2006), van de Vrande et al. (2009), Barge-Gil (2010), Drechsler and Natter (2012), and Ye et al. (2012). The few existing studies point to strategy factors, like offensive strategies, and to environmental factors, like uncertainty (turbulence) in the business sector. However, the factors may be different for the focal companies of this study, university spin-offs, such as connected with their short of time and management experience in dealing with complexity in extensive networks that cover the stakeholders needed to affect the socio-technical system.

Socio-technical systems are complex systems in which one or a set of technologies is dominant and changes detrimental to the system are prevented to take place by the impact from existing infrastructures, institutions and vested interests of main stakeholders, i.e., the interaction between society's complex infrastructures and human behavior (Geels, 2004). By adopting a multilevel approach to socio-technical systems, distinguishing between the niche level – where novelty is created, the regime level – structures of current practices and routines - and landscape level - processes of long term change, pathways to change (named

transitions) can be identified (Geels, 2002; Geels and Schot, 2007). According to this thinking, companies in niches cannot bring about change in the system themselves, but they can contribute to change by acting in well-selected powerful networks (platforms). Through a set of interrelated strategies in open innovation and gaining of resources, and through a strong market (customer) focus and increase of legitimacy, entrepreneurial companies may contribute to system changes, for example, by crossing the chasm and reaching early majority customers (Hockerts and Wüstenhagen, 2010; Markard and Truffer, 2008; Tilley and Parrish, 2009; Mohr et al., 2010).

University spin-off companies can be seen as a major channel of knowledge interaction between universities and the economy and society (Shane, 2004), but they generally suffer from lacking resources, like marketing and market knowledge, marketing skills and management skills, etc. (van Geenhuizen and Soetanto, 2009). However, according to evolutionary thinking, they may work as a trigger, breaking with path dependency, and open ways to changes in the system context (Balzat and Hanusch, 2004; Nooteboom and Stam, 2008; Thomson et al., 2011).

To our knowledge, no study to date has investigated responsible innovation and open innovation linked with system changes among university spin-off companies; but there are studies on merely open innovation among these companies by van Geenhuizen and Soetanto (2013) and van Geenhuizen and Ye (2013). In addition, a few studies directly connect entrepreneurial behavior among spin-offs or new entrants with the system context, like Hockerts and Wüstenhagen (2010). Accordingly, this paper contributes to the literature by connecting responsible innovation and open innovation on the micro-level using a specific category of high-technology start-ups, university spin-off companies. In addition, the paper questions the influence of *spatial* dimension in the networks concerned. We draw on a sample of 105 companies in addressing the following questions:

- (1) In which ways are spin-off companies involved in responsible research and innovation, and what is the relation with open innovation?
- (2) What is the influence of responsible innovation and open innovation on growth, and which network conditions may follow from this influence, including spatial ones?

2. Theoretical background

2.1 Open Innovation

Open innovation has changed the ‘landscape’ of innovation since the early 2000s. Learning in innovation has become an interactive process with involvement of a wide range of organizations, like suppliers, customers, competitors, universities, and public authorities (Chesbrough, 2003; Laursen and Saulter, 2006; Lichtenthaler and Lichtenthaler, 2009). Open innovation can be 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).

Three core processes are involved in open innovation (Enkel et al., 2009). First, there is an outside-in model meaning that innovation in the company benefits from external inputs (inbound), like advice from university technicians to spin-off companies in facility sharing at the university. Accordingly, innovation networks and customer community integration are increasingly relevant practices (Enkel et al., 2009). Secondly, there is an inside-out process, this refers to bringing ideas to market, selling IP, and enriching technology by transferring ideas to the outside environment. An example is participation in external companies gaining licensing fees. Companies having adopted this practice, focus on externalization of their knowledge and innovation in order to bring ideas to market faster than they could have done through internal learning and development. The third process is the ‘coupled’ process and refers to co-creation with complementary parties through alliances, joint ventures, in which ‘give and take’ are a basic condition for success. By combining the outside-in process to gain external knowledge with the inside-out process to bring ideas to market, the company and its partner(s) jointly develop and commercialize innovations. An example is co-creation with lead-users in which knowledge on specific customization is combined with a new technology. Co-creation is receiving an increased attention in the literature today.

Open innovation in itself is not a new phenomenon. Many companies were already practicing open innovation before the early 2000s, such as in outsourcing and research collaboration with a lead customer, but the urgency to practice open innovation in a conscious and systematic way has increased in the past decade due to a quicker speed of technology development and increasing global competition (Dahlander and Gann, 2011; van Geenhuizen and Ye, 2013; Huizingh, 2011). In the existing empirical studies on open innovation a distinction is made between two dimensions of this learning strategy, i.e., the size of the

external knowledge pool, named *capacity*, and the *diversity* in this knowledge pool (Laursen and Salter, 2006; Ye et al., 2012). Openness capacity can be seen as composed of different types of knowledge (subjects) and tie strength with the connected partners (depth). Openness diversity deals with heterogeneity among partners in the type of organizations involved, like universities, a large company as launching customer, a small company, public authorities, etc. These different dimensions are taken into account in the empirical analysis reported in this paper.

A common theoretical approach to companies' strategies is the resource-based view (Barney and Clark, 2007; Wernerfelt, 1995), in which a company's 'difficult to imitate resources' are seen as determining its competitive advantage. Accordingly, open innovation is adopted if the partner(s) provide resource complementarities, economies of scale, low cost new market entry, and (technological) capability building, etc., but also if the company owns sufficient resources by itself to 'afford' open innovation, like time and knowledge to identify the best partner and time and capabilities to manage the collaboration. There is not much understanding of what drives open innovation on the micro-level of companies. The few studies that exist, point to strategy factors as important influences on openness, like offensive strategies (enhancing growth) as opposed to defensive strategies in shaping openness (Chesbrough and Crowther, 2006; van de Vrande et al., 2009) and the choice for science-based innovation as opposed to engineering-based innovation, with the first facing rapidly changing environments and concomitant knowledge needs (Mohr et al., 2010), reason for a larger need for openness.

Aside from strategy factors, enabling factors provide the resources needed (time, skills) to benefit from open innovation, like through company size, size of founding teams, and experience in this team. Openness may increase with the increasing learning abilities as the firm size grows (Drechsler and Natter, 2012), but the increase may slow down followed by a decreasing return implied by locked-in routines (Cohen and Levinthal, 1990; Nelson and Winter, 1982; Dahlander and Gann, 2010). The size of the founding team may have contradictory effects, given that some studies indicate that a large size enhances strong learning in building the initial networks (Davidsson et al., 2006), however, in other studies, larger founding teams are seen as increasing the chance of 'social loafing' and reduce the learning in building networks (McShane and Travaglione, 2007; Robbins and Judge, 2011). Furthermore, pre-start experience, with the dimensions of breadth and depth, may also have impacts on open innovation.

And finally, factors in the external environment, like the urban environment and the business sector may also have an important influence. A highly urbanized environment could be favorable from a density and diversity perspective (partners, information), facilitating the establishment and maintenance of networks with good matching partners with regard to value alignment and open innovation (e.g. Chinitz, 1961; Jacobs, 1968; Glaeser et al., 1992; Feldman and Audretsch, 1999; Florida, 2012).

2.2 Transitions

We adopt a socio-technical system's perspective to responsible innovation (Geels, 2002; 2004). Such a perspective allows to view technical innovations which are needed to reach higher levels of sustainability or social well-being in their context, particularly in relation to factors that hamper market introduction of these innovations. Accordingly, merely technology does nothing, there are many examples in which the adoption of new technology has been prevented by social factors. The social factors include, for example, vested interests in the old technology and its infrastructure (like of gasoline producers in the case of electric cars) and institutions (like subsidies and taxation, and particular routines of insurance companies in medical healthcare), all preventing change in the socio-technical system.

In socio-technical system's theory it is emphasized that a single technology factor or social group cannot create a big transformation, instead, the whole socio-technical system - including institutions - should be aligned and coordinated to bring about a transition (Geels and Schot, 2007), though small companies acting in highly selective and strong networks of open innovation may contribute to transitions (Hellsmark and Jacobsson, 2009; Markard and Truffer, 2008; York and Venkatamaran, 2010). An important milestone in such development will be 'having crossed the chasm' and adoption of the innovation/technology by the early majority of the mass market (Mohr et al., 2010). However, the socio-technical systems involved may differ widely with regard to complexity, uncertainty, internal differences, etc. For example, the health sector seems more complex compared to the energy sector due to a high level of fragmentation such as based upon different therapeutic areas and composition of companies, and due to complexity from many different stakeholders, like insurance firms and national approval institutes (Rouse and Serban, 2011; Janssen and Moors, 2013).

3. Methodology

The research design is exploratory mainly using a quantitative approach in investigating involvement of 105 university spin-off companies in responsible innovation and in open innovation, and the importance of the networks concerned on growth of these companies. We draw on data from two technical universities, Delft University of Technology in Delft, the Netherlands, as a highly urbanized area, and Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, as a peripheral, less urbanized, area. No differences are assumed in the national innovation system in general, as the two countries share a somewhat risk-avoiding entrepreneurship culture (GEM, 2010), face similar scores on the main European Innovation Scoreboard indicators (ProInno Europe, 2011), and have relatively small domestic markets.

The population of companies satisfied important conditions: involved in knowledge created at the university, survived to 2006 with an age not older than 10 years, and served by at least one type of support from the incubation organization/university (150 in total). The overall response rate in 2006/7 was 70% and data were collected using a semi-structured questionnaire in face-to-face interviews (with principal manager) focusing on firm characteristics, e.g. type of innovation, product/service, market, firm size, founding team size and pre-start experience, profiles and openness of the knowledge networks. In 2011/12, data were collected for the same companies on growth (employment and turnover) and on changes in main network partners, using an e-mail questionnaire and website study.

4. Results

4.1 Involvement in Responsible Innovation

A distinction is made between a full involvement and a partial involvement in responsible innovation. The first means that all activity of the company is focused on a responsible innovation product or service, the last means that only part of the activity can be labeled as such. Note that in the current research, the processes that have led to responsible innovations, are not studied in detail, except for the underlying open innovation. This means that we cannot ‘track’ the values involved in interaction with society and economic actors.

A small majority of the sampled companies (56%) is engaged in responsible innovation, either full or partially (Table 1). Conversely, a good 40% of the companies is not dealing with responsible innovation. Involvement mostly refers to the medical sector and sustainable energy, both at 11% of all fully involved companies, the last is also partially involved (at a level of 6%). Sustainable mobility (including vehicle technology) is third at 7% of all companies with full involvement and also with partial involvement. Waste treatment and recycling is fourth, at 6% of all fully involved companies.

The medical sector includes design of instruments for minimal invasive surgery, ergonomic furniture, and practical help in daily care of elderly, as well as new medicines. Sustainable energy includes new types of solar cells, improved batteries, improved windmills (rotor blades), improved turbines, but also energy saving in using refrigerators (cooling systems).

Table 1. Application area of responsible innovation products/services (105 spin-offs)

Application area	Full involvement		Partial involvement	
	Abs.	%	Abs.	%
Medical care and cure	11	10.5	0	-
Sustainable energy ^{a)}	11	10.5	6	5.7
Sustainable mobility, vehicle technology	7	6.7	7	6.7
Efficient industrial processes	1	1.0	5	4.8
Efficient waste treatment (recycling)	6	5.7	0	-
Sustainable buildings and safety	4	3.8	1	1.0
Totals (N = 59 spin-offs)	40		19	

a) including energy efficiency

In a next step, we ‘refine’ the class of ‘responsible innovators’ to those involved in responsible products, processes etc. only at a relatively high level of innovativeness (Annex A). Accordingly, dependent on a narrow definition and a broader definition, we qualify 27% and 33% of all sampled spin-off companies as ‘highly innovative responsible innovators’.

4.2 Adoption of Open Innovation

We explore to what extent responsible innovators have adopted open innovation practices and measure open innovation using two dimensions, i.e. openness capacity and openness diversity (Ye et al., 2012). Openness *capacity*, as the ‘size’ of the external knowledge pool, is

measured as a two-dimensional variable composed of breadth and depth (Laursen and Salter, 2006) (see Annex B). Breadth, as number of different types of knowledge acquired, and depth, as tie strength between the company and its partners, constitute the knowledge pool that is actually accessed. Note that the influence of tie strength, e.g. on growth and innovation, is context dependent, for example, with regard to social status of the individuals involved (Lin et al., 1981). The mathematical modelling is special in the sense that it assigns weights to three strength variables, using entropy-weight method; this measures the effective amount of information of the data and better reflects reality than other measures.

In addition, openness *diversity* describes the heterogeneity of partners' social background, including spatial orientation (local versus regional). A distinction is made between partners from large companies and from small ones, government representatives at high level, university professors, lead customers, family and friends, etc.

We may assume that responsible innovation requires relatively high levels of openness in knowledge relations. Comparing openness capacity and openness diversity between responsible innovators and other spin-off companies brings to light that the first are indeed more engaged in open relations, but only as far as capacity is concerned (Table 2). The results are robust because using both the narrow and broad definition of responsible innovators yields statistically significant results. Responsible innovators have an average score of 5.5 compared to 4.4 among other spin-offs. Apparently, responsible innovators have to stretch their knowledge into different disciplines and themes, therefore a larger knowledge pool is needed. However, these small start-up companies tend to have limited resources (time, experience) and cannot afford building and maintaining relationships with many different partners and groups at the same time.

Table 2 Scores on openness capacity and diversity

		Responsible Innovators narrowly defined (N=28)	Other companies (N=77)
Openness capacity a)	- average	5.50	4.39
	- s.d.	2.73	2.44
	- min-max	1.51-11.67	1.08-12.35
	t-test	-1.99**	
Openness diversity	- average	0.80	0.77
	- s.d.	0.16	0.13
	- min-max	0-0.90	0-0.89
	t-test	-1.09	

*p<0.1; **p<0.05

a) Using the somewhat broader definition of responsible innovators (N=35) produces similar results: averages of 5.22 versus 4.42 and a T test result for openness capacity (- 1.52) that is significant (p<0.1).

In an exploration of responsible innovation as a driver of open innovation (using optimal models) the results indicate that responsible innovation plays a role among various other factors (Table 3). Remarkably, while many factors are not significant for the two dimensions of openness (capacity and diversity) or - if significant - show different directions of influence, being involved in responsible innovation is significant for both dimensions with a positive influence. The results also indicate that the type of urban location plays a role, indicating a trend for more diversity in the open networks among spin-offs in peripheral, less urbanized area. This finding complies with the results of Teirlinck and Spithoven (2008) who found higher degrees of openness, including outsourcing and customer relations, in knowledge networks among firms in less urbanized regions.

Table 3 Stepwise regression analysis of openness: optimal outcomes a)

	Openness Capacity (knowledge pool)	Openness Diversity (knowledge partners)
	β (s.e.)	β (s.e.)
<i>Enabling factors</i>		
Company size	-0.28 (0.11)**	0.91 (0.10)***
Size of founding team	0.81 (0.25)***	-0.30 (0.21)
Pre-start experience (breadth)	-	0.19 (0.08)**
Pre-start experience (depth)	-0.05 (0.02)**	-
<i>Strategy factors</i>		
Nature of innovation activity (science-based = 1)	-	0.42 (0.18)**
Aim of innovation (responsible innovation narrowly defined = 1)	0.52 (0.21)**	0.39 (0.18)**
<i>External factors</i>		
Business environment (competition)	0.57 (0.18)***	-
Urban/regional environment (isolated/peripheral=1)	-	0.43 (0.16)***
N b)		
	102	102
F	6.44***	16.96***
R ²	0.25	0.52
Root MSE	0.84	0.72

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

a) Common diagnostics have been performed: linear regression diagnostics, addressing e.g. data causing bias, test for normality of residuals and for heteroscedasticity of residuals, as well as multicollinearity and endogeneity tests, all indicating absence of serious impacts on the results.

b) Three outliers have been removed (different cases for the two models).

4.3 Growth Trends

Next we address the question whether growth among responsible innovators differs from growth among other spin-offs, and how responsible innovation if interacting with open innovation may influence growth of the companies.

It is not clear from the literature whether responsible innovators show different growth trends compared to other companies. Derived from the idea that more radical innovations are involved in solving societal problems, one may expect a slower growth due to resistance from traditional solutions or from current technologies and institutions (Geels, 2002). On the other hand, one may assume a stronger growth if the solutions are developed in interaction with (future) users and other stakeholders, and are supported with subsidies within national supportive policies. With regard to employment, responsible innovators tend to be less exposed to failure (cease to exist), and tend to better perform with regard to strong growth (Table 4). The last is witnessed by a share of 36% among responsible innovators (narrow definition) compared to 18% among other spin-off companies. The relationship is significant at the $p=0.1$ level.

Table 4 Employment growth

Employment	Responsible innovators narrowly defined a)		Other spin-offs	
		%		%
Ceased to exist	2	7.1	11	14.3
Negative/no growth	12	42.9	25	32.5
Low/medium growth	4	14.3	27	35.1
Strong growth	10	35.7	14	18.2
Total	28	100	77	100

Pearson $\chi^2=7.24$, $p=0.07$

a) Using the broader definition of responsible innovators (N=35) does not produce significant results.

Table 5 Turnover growth

Turnover	Responsible innovators narrowly defined a)		Other spin-offs	
		%		%
Ceased to exist/ negative growth	6	21.4	16	21.1
No growth	9	32.1	35	46.1
Low/medium growth	4	14.3	17	22.4
Strong growth	9	32.1	8	10.5
Total	28	100	76*	100

Pearson $\chi^2=7.45$, $p=0.06$ *one missing value

a) Using the broader definition of responsible innovators (N=35) does produces significant results.

With regard to turnover (Table 5), spin-offs involved in responsible innovation tend to perform remarkably better in the category of strong growth than their counterparts, as witnessed by 31 versus 9% and 32 versus 11% in this growth category. The relationship between turnover and subsamples of responsible innovators is statistically significant (both definitions of responsible innovators).

Next we explore whether responsible innovators having adopted open innovation practices, grow at a different pace compared to other spin-offs, regarding employment and turnover (a simplified model) (Table 6). The narrow definition of responsible innovation is used in the model as it leads to the best outcomes compared to the broadly defined one, whereas firm age as well as growth ambition are used as control variables. The interesting results are the moderating effects between responsible innovation and openness in knowledge relations, indicating an opposite trend between interacting with openness capacity (positive) and with openness diversity (negative). Open innovation tends to play a role in the influence of responsible innovation on growth, with a large diversity hampering growth and a large capacity (pool of knowledge) stimulating growth.

Accordingly, the best strategy for responsible innovators among small spin-off companies seems, given their limited resources, a ‘selective openness’, i.e., to be open towards the most knowledgeable partner and use the few resources to identify such a partner and deepen the relationship.

Table 6 A simplified ordinal regression analysis of growth (2005-2010), optimal model ^{a)}

	Growth (employment)	Growth (turnover)
	β (s.e.)	β (s.e.)
Openness Capacity (knowledge pool)	-0.27 (0.18)	0.20 (0.19)
Openness Diversity (knowledge partners)	0.27 (0.19)	-0.38 (0.20)*
Aim of innovation (responsible innovation =1)	0.33 (0.46)	0.29 (0.48)
<i>Moderating effects</i>		
Responsible Innovation x Openness Capacity	0.25 (0.41)	0.78 (0.45)*
Responsible Innovation x Openness Diversity	-0.95 (0.46)**	-0.55 (0.46)
<i>Control variables</i>		
Firm age ^{b)}	-0.26 (0.25)	-0.56 (0.25)**
Growth strategy	0.52 (0.20)**	0.32 (0.20)
N	105	104
LR χ^2	17.38**	17.70**
Log likelihood	-130.30	-127.56
Pseudo R ²	0.06	0.06

* p<0.1; ** p<0.05

a) Diagnostics for these models, particularly ordered models is extremely difficult, and therefore not performed.

b) The negative sign indicates that mainly older firms are hit by the economic crisis starting in 2008.

5. Spatial conditions

Our results so far reveal that responsible innovation drives openness in knowledge networks both in capacity and diversity, alongside other factors. One of these factors is the location, namely, being located in a peripheral region tends to enhance openness with regard to partner diversity. At the same time, spin-off firms as ‘responsible’ innovators are short in time and in experience forcing them to select the best partner and manage the knowledge networks using a minimum effort. This ‘pressing’ situation is underpinned by a negative influence of diversity in networks on firm growth.

The need for a ‘selective openness’ could mean to connect with one large company as launching customer (co-creation) and eventually with a prominent investor from the sector. The best strategy, in terms of a low management effort, seems thus to establish just one or two single connections that on their turn make a wider diversity of network partners (or platforms) accessible. Such ‘selected’ networks cannot be built in less urbanized areas in an easy fashion, due to less density of the key partners concerned (Jacobs, 1968; Florida, 2002). In addition, responsible innovation requires what might be named ‘value proximity’ between the network partners. With ‘value proximity’ we mean that the partners share a sufficient understanding of the core values at hand and act accordingly in their part of the innovation process. Value proximity can be seen as a specific kind of social proximity (Boschma, 2005) that can only be created by frequent face-to-face interaction in permanent co-location, and most probably to a smaller extent through business meetings and personnel detachment only. According to this line of reasoning, it seems that small responsible innovators are facing more limitations and a need for stronger efforts in peripheral, less urbanized, regions compared to large metropolitan areas in finding partners that match. There may be one main exception to this situation, and that is if responsible innovation is strongly connected with natural resources specifically available in peripheral regions and specialized clusters - with the main actors co-located - have emerged there, like in the case of wind energy and physical space for experimentation.

6. Discussion

This paper has connected open innovation to so-called responsible innovation, and has extended the issue to growth and network conditions among a specific type of high-tech start-

ups, university spin-offs. The main distinctive characteristic of these companies is a lack of resources, including time, management experience, skills concerning accessing the market, and investment capital. A sample of 105 of such companies in the Netherlands and Norway was used. The study demonstrated that almost 60% of the sampled companies are engaged in responsible innovation, with medical care/cure, sustainable energy, sustainable mobility, and waste treatment/recycling as the largest sectors, and that a good 40% was not involved in responsible innovation.

The emphasis in the study was on open innovation as an important process characteristic of responsible research and innovation. The results reveal that responsible innovation drives openness both in capacity and diversity, alongside other factors. Results on growth of the spin-off companies pointed, however, to the need for a 'selective openness' regarding types of networks partners, which could mean to connect with one/two large companies as launching customer and to connect with a public authority if necessary for experimentation and implementation.

Despite the interesting results, this study suffers from some limitations. The first lies in the relatively limited definition of responsible innovation, which is a qualification based on the product/services and underlying open innovation practices, ignoring the role of values in interaction with society. The second limitation originates from the countries where the sample of university spin-off companies was drawn, i.e. the Netherlands and Norway. The results can be generalized on the basis of similarity with regional economies in the maritime cluster and energy clusters, like in Sweden, Denmark and parts of the northern UK (e.g. Scotland). This is a small part of the European Union, whereas the interpretation of responsible innovation may be culturally defined and context-dependent across the European Union countries.

Future research could first of all be aimed at a more comprehensive construction of the responsible innovation variable connected with values being negotiated and finally agreed in open innovation with societal actors. In addition, the context-dependence of the value component in responsible innovation needs to be addressed as a future subject of research across European Union countries. Secondly, ways need to be found to increase involvement of university spin-offs in responsible innovation, even though their lack of resources places limits on the possible number of different partners and possible complexity in open innovation they can cope with. Preliminary evidence does indicate that selectivity (partners in open innovation) is of paramount importance causing a disadvantageous situation for small

firms in peripheral regions, but calls for a rigorous testing, which leads to a *third* area of future research, moving away from the company to the network and towards changes in socio-technical systems (e.g. Hermans et al., 2012). Accordingly, in longitudinal research, the most prominent or powerful partners and their networks need to be identified enabling impact on transitions in socio-technical systems.

Annex A Involvement in responsible innovation and level of innovativeness

Strength of involvement and level of innovativeness (category 1-7)	Abs.	%
1. Full involvement and highly innovative	28	26.7
2. Partial involvement and highly innovative	7	6.7
3. Full involvement and medium innovative	8	7.6
4. Partial involvement and medium innovative	5	4.8
5. Full/partial involved and low innovative	11	10.5
6. Not involved and highly innovative	14	13.3
7. Not involved and medium/low innovative	32	30.5
Totals	105	

We define ‘responsible innovators’ as category 1 (28 companies) or as category 1 plus category 2 (35 companies).

Annex B Openness capacity and openness diversity

The value of *openness capacity* was calculated as:

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

where n is the number of types of external knowledge, like market, technology, etc. The breadth B_i is the counted number of partners within a type of knowledge.

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 frequency of interaction (r), duration of relationship (u), and entrepreneurs’ assessment of closeness of the relationship (c , M -rank categorical variable) calculated as:

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

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 contamination of frequency of interaction. These variables will be further normalized (for each variable, min: 0; max: 1). Next, a weighting method is used derived from thermodynamic theories. 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. If there are m criteria and n objects which need to be evaluated, the entropy of the i th criterion is defined as H_i :

$$H_i = -k \sum_{j=1}^n f_{ij} \ln(f_{ij}) \quad (i = 1, 2, \dots, m) \quad (B.3)$$

where $f_{ij} = \frac{r_{ij}}{\sum_{j=1}^n r_{ij}}$, and $k = \frac{1}{\ln(n)}$. And we assume that when $f_{ij} = 0$, $f_{ij} \ln(f_{ij}) = 0$. Basically, the larger the entropy H_i , 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 cannot provide enough information or distinction to differentiate various strengths of tie. Therefore, the entropy weight of the i th criterion can be calculated by:

$$w_i = (1 - H_i) / (m - \sum_{i=1}^m H_i) \quad (\text{B.4})$$

The entropy weights for the three indicators of tie strength can now 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:

$$D_j = w_u u_j^* + w_r r_j^* + w_c c_j^* \quad (\text{B.5})$$

where for D_j , a higher value indicates a relatively tighter relationship, thus a deeper “depth” (min: 0; max: 1).

Openness diversity describes the heterogeneity of partners’ socio-economic background, including spatial orientation. The knowledge partner diversity is calculated as:

$$Der = (1 + \frac{EI}{2}) \times Hs \quad (\text{B.6})$$

where $Hs = 1 - \sum_{k=1}^8 (\frac{a_k}{N})^2$, and (B.7)

where a_k is the number of partners with a different socio-economic background, using the following categories: a large or medium-sized business, governments, university, small business, family or friend, venture capitalists, lead customers and others. N is the total number of partners a firm interacts with, with a higher value indicating a higher level of social background difference (min: 0; max: 1). Further, EI is calculated as

$$EI = \frac{E_p - I_p}{E_p + I_p} \quad (\text{B.8})$$

where E_p is the number of external, non-local, partners, reached within one hour car driving, 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).

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