Greenagers out in Town – The Collaboration Patterns of Entrepreneurial, Green Firms

Paper for the Institute for small business and entrepreneurship 2015 Conference

Glasgow, November 11-12

Jesper Lindgaard Christensen
Associate Professor,
Department of Business and Management, Fibigerstræde 11, 9220 Aalborg Ø, Aalborg University, Denmark. jlc@business.aau.dk, tlf. 0045 99408261

Daniel S. Hain
Ph.d. student, Aalborg University, Department of Business and Management, Denmark

Letícia Antunes Nogueira
Ph.d. student, Aalborg University, Department of Business and Management, Denmark

ABSTRACT

Objectives: We analyze if firms engaged in 'green' innovation activities, display different collaboration patterns with external partners compared to otherwise similar 'non-green' companies. This overall research question is triggered by the presumption that green innovations requires firms to source in knowledge and other resources in a distinct manner. Green innovations are often interwoven with other parts of the system and draw upon different knowledge bases.

Prior Work: Generally, extant literature point out that networks impact the innovative performance of firms (Pittaway et al., 2004, Najfian and Colabi, 2014, Huggins et al., 2012, Hao and Yu, 2012, Powell et al., 1996, Hewitt-Dundas, 2006), why they collaborate (Tether, 2002, Miotti and Sachwald, 2003), and what different partners may mean in innovation activities (Nieto and Santamaria, 2007, Laursen and Salter, 2006). However, the findings in this literature cannot be directly applied to the case of green innovators because of the special characteristics of these innovations (eg. van Kleef and Roome, 2007; De Marchi and Grandinetti, 2013; Cainelli et al., 2015; Cuerva et at., 2014; Del Rio et al., 2013, Ghisette et al., 2015, De Marchi, 2012).

Approach: We use both quantitative and qualitative approaches. We use data from a recent (2014) special section of the CIS survey in Denmark, which included questions on energy innovation. Our dataset contains 2.087 firms, of which 550 have such activities. Frequency and regression analyses test hypotheses derived from earlier literature. The qualitative, single-case study illuminates some of the mechanisms that were only indicative in the quantitative analysis.

Results: Firms who introduce 'green' innovations are notably more likely to engage in collective innovation activities than non-green innovators. But we find, counter to expectations, that overall their collaboration patterns in terms of which actors they interact with are almost exactly as in other firms, only with higher frequency. We further found weak correlation between firm's cooperation diversity and innovative performance, particularly for green innovation. We ascribe this to the long time-lags between product innovation and market penetration in renewable energy.

Implications: For green innovators we point to the need to actively engage in networks to broaden their knowledge base, and access a variety of capabilities and resources that are indispensable to the organization. Our results also show that policies for enhancing links between firms engaged in green innovations are important but need not be different for energy innovators.

Value: The study is relevant and important as it reveals the importance and character of networking for the development of new, green technologies. Such networking activities does, however, require competences. Moreover, the study point out that expectations to a linear correlation between input and output should be moderated.

JEL Classification: O31, O32, Q4, L26

Keywords: green innovation, collaboration capabilities, innovation networks, innovation survey.

1. Introduction

Are network activities of firms determined by their technologies, industries, or other characteristics? Innovation increasingly originates from diverse and complex knowledge bases. This makes collaboration activities more important and firms increasingly pursue innovation in interactions with partners and the institutional system in which they are embedded (Powell et al., 1996, Lundvall, 1992, 1993). The research question is if the way networking is pursued is something generic or if it is linked to the type of activity firms do and/or their characteristics. In this paper, we analyse if firms engaged in 'green' innovation activities, in our case operationalized as innovations in renewable energy (RE), display different collaboration patterns with external partners compared to otherwise similar 'non-green' companies. This overall research question is triggered by the presumption that green innovations require firms to source in knowledge, capabilities and other resources in a distinct manner.

We justify this presumption with three main arguments. First, green innovations are often interwoven with other parts of the system, in the sense that, for being successfully taken to market, solutions in renewable energy require integration with other elements in the energy system (Foray and Grübler, 1996, Rennings and Rammer, 2009, De Marchi and Grandinetti, 2013, Horbach et al., 2013). Second, introducing and producing RE innovations involves relatively more complex knowledge bases compared to most other innovations (De Marchi and Grandinetti, 2013, De Marchi, 2012, Marin et al., 2015). Finally, innovations in renewable energy generally involve higher capital costs until they reach a commercial level, which could indicate the need to engage with more actors for mobilizing necessary resources (Marin et al., 2015).

These features of energy innovation have implications for how firms link to actors outside the firm. Thus, in line with previous research (eg. van Kleef and Roome, 2007; De Marchi and Grandinetti, 2013; Cainelli et al., 2015; Cuerva et at., 2014; Del Rio et al., 2013, Ghisette et al., 2015, De Marchi, 2012) we expect green innovating firms to show substantially different interaction and cooperation with partners such as customers, competitors, the public sector and suppliers compared with innovators in conventional technologies.

Furthermore, we posit that 'green innovations' often suffer from the double externality problem (Rennings 2000) which refers to the sum of externalities described in environmental economics literature, and R&D economics literature. That is, firms lack incentives do adopt environmentally friendly solutions at the expense of the current solutions, while at the same time they fear not being able to capture rents from developing these innovations, as the resulting technologies may spill over, considering their character as public-goods. Because of the double externality problem, firms tend to 'underperform' initially when compared to existing non-green solutions. The implication from this is that we expect to find non-linear and different performances in firms involved with green innovations than in otherwise similar firms. Moreover, in most literature the collaboration activities are assumed to unfold frictionless. We instead presume that it requires competences, search, and engagement to collaborate, and we include also that collaboration often meet obstacles. Some of the above-mentioned literature has got some of the way to an understanding of this but there is a need for additional research on this topical problem area. One example why results from this research could potentially be important and have practical implications is that most countries design specific energy policies as well as network policies. It is not clear if there is a need for differentiated policies in these areas.

On a more general level a large body of literature has extensively embarked on the dynamics of innovation networks (Noteboom, 1994, Pittaway et al., 2004), with a few recent studies having discussed this dynamics in light of green entrepreneurship (De Marchi, 2012, De Marchi and Grandinetti, 2013, van Kleef and Roome, 2007, Horbach et al., 2013, Cainelli et al., 2015, Cuerva et al., 2014, Triguero et al., 2013). Whereas this literature almost solely uses quantitative data, we use both quantitative and qualitative data, as our ambition is to not only show the collaboration patterns but also to explain the underlying background and motivations for engaging in collaboration. The quantitative data stems from a recent survey, which is a special section of the CIS survey in Denmark including a set of questions on energy related innovation activities. Our dataset contains 2.087 firms, of which 550 indicate to be engaged in research or innovation activities related to the production, distribution, storage or consumption of energy. Our qualitative data consist of a single case study allowing us to dig deeper into understanding the motivations behind our aggregate findings (Yin, 2003). The case also offers empirical insights into the relationship between collaboration activities and the process of developing and stretching organizational capabilities.

Using frequency analysis and propensity score matching we indeed find that firms that introduce 'green' innovations are notably more likely to engage in collective innovation activities than non-green innovators. We find, though, counter to expectations, that their collaboration patterns in terms of with which other actors they interact are almost exactly as in other firms, only the frequency of listing particular partners are higher. The exception from this pattern is that entrepreneurial innovators in renewable energy have a higher propensity to collaborate with universities.

The study is relevant and important in that it reveals the character of a 'sub-system of innovation', in which small, entrepreneurial firms stretch their capabilities to enter markets for new, green technologies, hence a process that Hockerts and Wüstenberger (2010) termed 'Davids' challenging the 'Goliaths' (incumbents) of the energy industry. Entrepreneurs have been claimed to be particular important to driving eco-innovations (Wagner and Llerena, 2011). We provide a conceptual complement to innovation system theory, and we provide a useful guidance for more effective policy making in the field. Moreover, we also contribute to management practice, by indicating that effective inter-firm collaboration is particularly important for innovation related to RE. Likewise, we indicate how collaboration activities with external partners interact with organizational capabilities and are carried by investments in human resources.

The paper proceeds with a theoretical, literature-based discussion on why and how firms collaborate on innovation leading to the question, if and why we should expect differences in the collaboration on innovation if firms are engaged in green innovations. Section three explains our approach and data. The fourth section has our findings from work on survey data followed by section five, which presents our case study. Discussion on the results, conclusions, and implications are laid out in the final section six.

2. Theoretical background: why and how firms collaborate

In the following, we survey existing theoretical and empirical literature discussing how, when, and why firms collaborate with other organisations in their innovation activities. The general idea behind this review of literature and ideas on inter-firm collaboration is to arrive at some expectations on the case of green, entrepreneurial firms: could they be expected to differ from 'ordinary' firms? If so, how? Hence, we consider four issues in this theoretical background: (i.) How innovation is now understood as taking place in an interaction with other actors and the institutional system, (ii.) why firms collaborate and what it takes in terms of the capabilities to interact, (iii.) what drives collaboration, in terms of the actors' need for knowledge, and the consequences of this for the number and types of collaboration partners, and finally (iv.) why (if) the case of 'green' innovations should require other resources than conventional innovations.

2.1. Innovation in interaction

Over the past few decades, there have been considerable developments in the perception of innovation processes. Among several, one of the achievements in the understanding of innovation is that the generation and use of different kinds of knowledge in the innovative efforts of enterprises is a key factor for their competitiveness. Another key insight is that innovation is often a result of a collaborate effort. Nowadays there is consensus that technological innovation takes place in an interactive learning process between varieties of actors at all levels in the economy (Lundvall, 1992). Moreover, multiple sources of information and pluralistic patterns of collaboration seem to be the rule rather than the exception. The data from the Community Innovation Survey (CIS) have been used to demonstrate that firms often find their sources of inspiration for innovation from other organisations, and that they find these sources of inspiration with a multitude rather than with a single external partner (Smith, 2001). Likewise, work on innovation systems done at the OECD (1999), revealed that there is in fact a considerable variation between national innovation systems and industries in terms of the extent to which firms interact with different collaboration partners, and in terms of whether collaboration is pursued with domestic or international partners. Freeman (1996) illuminated how the progress in the understanding of the innovation process also informs the role of interactions in the 'green' economy.

Generally, extant literature point out that networks impact the innovative performance of firms (Pittaway et al., 2004, Najfian and Colabi, 2014, Huggins et al., 2012, Hao and Yu, 2012, Powell et al., 1996, Hewitt-Dundas, 2006), why they collaborate (Tether, 2002, Miotti and Sachwald, 2003), and what different partners may mean in innovation activities (Nieto and Santamaria, 2007, Laursen and Salter, 2006). These types of literature provide relevant insights, and we take them as a point of departure to developing propositions.

2.2. Why collaborate on innovation, and the requirements for it

Different strands of even early literature have laid out the reasons why firms tend to collaborate on innovation. Hence, in the early 1990s literature on strategic alliances (Hagedorn, 1993, 1996) provide insight into motives for collaboration and partnerships, and literature on innovation systems (Lundvall, 1992, Nelson, 1993) point out that collaboration is pursued with different types of partners in different contexts and that collaboration is governed by the institutional set up of the systems.

Literature on absorptive capacity to assimilate knowledge from outside (Cohen and Levinthal, 1989, 1990) points to that collaboration requires capabilities and build-up of internal resources for effective collaboration. Related, the literature on organizational capabilities approaches the issue of collaborations and offers insights on their role for capability building, which leads to competitive advantage (Helfat and Lieberman, 2002; Dosi and Marengo, 2007). This stream of literature also leads up to a literature on 'relational capability' (Lorenzoni and Lipparini, 1999), which influences efficiency and effectiveness of knowledge transfer between actors.

Hence, a critical success factor in the innovation process is seen in the capability of firms to find, select and absorb knowledge relevant for innovation (Cohen and Levinthal, 1989, 1990). This capability is affected by the type of knowledge being exchanged (i.e. embodied or disembodied, codified or tacit, one-sided or interactive) and the direct interaction among actors of an innovation system may facilitate efficient transfer of certain types of knowledge (Granovetter, 1973, Hansen, 2000, Boschma, 2005). Because knowledge-based competition has gained increasing importance firms value co-operative relations with firms and institutions with complimentary competencies. Cooperative innovative efforts contributes to staying abreast of the rapid pace of innovation, characterized by knowledge quickly becoming obsolete and, related, the fact that innovation processes often require integration of diverse technologies and knowledge bases (Miotti and Sachwald, 2003, Rennings and Rammer, 2009, Granstrand et al., 1997). In this setting, firms reduce the costs, risks, and uncertainties associated with innovation through innovation networking (Tether, 2002). To successfully reap the benefits of innovation collaboration firms need to select collaboration partners, however, the technological capabilities that potential partners possess is not always observable (Hagedoorn, 1993) and will require both a mutually beneficial partnership (evaluated ex ante) (Veugelers, 1998), and skills in relation to managing the actual collaboration (Ritter and Gemünden, 2003)[1].

Related, we also propose that the issue of capabilities and networking has a double role in this context. One role of collaboration/networking is as a mean to source in complementary competences, that the firm is not able to develop simply by stretching their own existing capabilities, hence bridging a resource gap. Another role is that it requires both resources and capabilities to construct, configure, and manage networks, in the literature often denoted 'network competence' (e.g. Ritter and Gemünden, 2003), although it has had several similar wordings such as 'relational capability' (Lorenzoni and Lipparini, 1999, Dyer and Singh, 1998), 'network capabilities' (Walter et al., 2006), and 'interfirm partnering competence' (Johnson and Sohi, 2003). This networking capability has been found to impact significantly on the innovative performance of firms (Hao and Yu, 2012).

A similar way of addressing this issue is through the term 'interpreneurship', which, to us, indicates that efficient and effective networking requires initiative, search, and engagement in the construction of networks, and it requires resources and capabilities for the executional part of the networking. The latter part, resources and capabilities for management of networks, has been extensively discussed in the literature (Ritter and Gemünden, 2003, Huggins and Thompson, 2015), but we posit that a full picture of relevant networking competences also require the former part – the search, engagement, construction part of networking. Hence, we denote the full range of network capabilities 'interpreneurship capabilities'.

Despite the fact that some parts of the literature points to the need for capabilities to create and manage networks, as reviewed above, we find that the existing literature has under-emphasized the problems related to establishment and management of networking. We therefore propose that networking for innovation is not pursued in a smooth, unconstrained manner that produces the most optimal solutions and partnering. Rather, firms may encounter barriers in both finding their partners for innovation and in the actual collaboration and they will outweigh expected benefits against search costs and collaboration costs.

2.3 Types of knowledge, types and number of collaboration partners

Huggins and Thompson (2015) propose that the relationship between entrepreneurship, innovation and (regional) growth depends on the network dynamics related to the nature of 1) the characteristics of the firms, 2) the knowledge used for innovation and 3) the spatial nature of the networks between providers and users of knowledge. In this paper we do not embark on the regional dimension but argue in a similar vein that the two first-mentioned dimensions are essential to understand the 'green' network dynamics. Later, in our empirical analysis, we explore the first dimension, the characteristics of the firms, by comparing green vs. other firms. We explore the second dimension, the knowledge used for innovation, by analysing their networking activities in comparison with their internal build-up of capabilities. A resource-based view of the firm (Barney, 1991, Wenneberg, 1984) would lead to firms substituting internal build-up of capabilities with external collaboration

[1] Substantial parts of the early knowledge on innovation networks and –collaboration was based on studies of R&D-collaboration and strategic alliances. In the past couple of decades there has been a much sharper distinction between these two phenomena. In spite of this caveat, the literature on R&D collaboration and the corresponding empirical studies have been helpful in providing explanations of the motives for and patterns in collaboration.

due to constraints on availability of resources. However, the arguments above and in the network competence literature indicate that simultaneous internal build-up of capabilities and build-up of external collaboration and competences for this is an expedient way forward. We later explore these two contradicting propositions empirically.

In a dynamic perspective the types of collaboration partners are likely to change over the life cycle of technological evolution. We expect that what could be termed 'upstream' sources/collaboration partners (universities, research organisations) are relatively more important in the early stage of development whereas 'downstream' sources are more important when the technology gets more mature and closer to market (Laursen and Salter, 2006). Consequently, the number of different collaboration partners at specific points of time over the technology evolution might remain constant but be of a very different configuration. Derived from this argument it is likely that the number of collaboration partners will be highest when firms are in a 'middle' position between still exploiting upstream sources while at the same time starting to orient themselves towards sources closer to market.

2.4 Application to green innovation and propositions

Several of the features of collaboration discussed in the literature apply generally to any (small) firm. But we expect that for green firms, especially in RE, the above-mentioned effects will be both amplified and different in some respects.

First, we expect that the energy industry structure has an impact on the collaboration activities of players. Switching to a renewable energy paradigm is a gradual process, and therefore innovations need to be integrated with existing structures of the system. This builds to the interconnectivity that represent the systemic character of innovations in general. As a consequence, the energy sector is often described as a dual structure (Hockerts and Wustenberger, 2010) where on the one hand a number of incumbents and large infrastructures dominate and produces a lock-in of technological evolution and on the other hand there are a number of entrepreneurial small innovators. In this situation we would expect the small, entrepreneurial firms engaged in green innovations to have a higher propensity to collaborate with external partners in order to compensate for the lack of economies of scale.

We propose: 1. Green, entrepreneurial firms will have a higher propensity to collaborate with external partners than non-green innovators.

Second, in line with earlier studies as reviewed above, we would expect a difference between green and non-green innovations regarding who they collaborate with. This propensity to collaborate is reinforced by the fact that green innovations often interact with several, complimentary knowledge bases (Horbach et al., 2013, De Marchi and Grandinetti, 2013, Marin et al., 2015). Nevertheless, green entrepreneurial firms are at the outset often built around a single-product or technology, meaning that their competences are narrowly built around a particular knowledge base. Hence, in order to thrive in a complex system, they may need to collaborate with a set of diverse types of partners.

We propose: 2. Green, entrepreneurial firms will have a more diverse set of collaboration partners than non-green innovators.

Third, in many cases, young entrepreneurial firms engaged in green innovations are more project-based or technology-based as opposed to firms who encompasses a broader range of the value chain. These types of firms will often have little turn-over at all, and be reliant in their business model on being acquired by firms who are in the manufacturing part of the value chain. In some respects they resemble firms in pharmaceuticals who typically face long time-lags between input and output (R&D and market), and likewise often do not have a product ready for the market before being acquired. This jeopardizes a linear relationship between input factors we would normally consider relevant for spurring output factors.

We propose: 3. Green, entrepreneurial firms will, to a higher extent, have non-linear or absent correlations between input factors and output compared to non-green innovators.

In the following we explain our data and empirical approach for analysing these questions. Moreover, it is clear that a number of the variables we discussed so far needs a closer operationalization and definition.

3 Data and methodologies

3.1. Quantitative analyses

Our basic research approach is to identify entrepreneurial firms who introduced 'green' innovations, and compare interaction patterns with external partners in these firms with collaboration patterns displayed by nonenergy innovating, firms. With respect to defining ‘entrepreneurial’ we take, as the point of departure, the firms that claimed to be innovative as being entrepreneurial. Our data allows us to apply more fine-grained definitions of entrepreneurial in the analysis such as separating firms using the innovation intensity as a yardstick. A third, additional operationalization, is that they need to be both innovative and young/small to be termed entrepreneurial. However, these additional definitions are only used in robustness checks of the results.

The data stems from a recent survey, which is a special section of the Community Innovation Survey (CIS) (OECD, 1997) survey in Denmark including a set of questions on energy related innovation activities. These questions were formulated by the authors. The survey was administrated by Statistics Denmark as part of the mandatory CIS for Denmark. The set of questions we inserted on RE were voluntary. Questionnaires were send out in 2014, and the survey closed in December. After cleaning the data our dataset contains 2.087 firms, of which 550 indicate to be engaged in research or innovation activities related to the energy sector. This includes both firms producing and distributing energy, firms involved in the supply chain, doing industrial products and processes that enable the building of energy production facilities, as well as firms offering services for this sector (O&M, logistics, installation, engineering and design etc.). The sample includes both firms that actually introduced innovation (180), firms that started but did not complete RE innovation projects (160) and firms that considered RE innovation but did not start such projects (230). ‘Green’ firms generally are hard to identify (Shapira et al., 2014). Survey-based approaches to identify them entail disadvantages such as low response-rates, difficulties in defining the relevant sample etc. (Shapira et al., 2014, Christensen and Hain, 2016) but they also have advantages over the alternatives. The survey questions had an identifier question that aided respondents to see if they should be included in the ‘green’ activities category. Table 1 shows the data on three structural characteristics, size, age, location and grouped in innovative and non-innovative firms.

Table 1: Descriptive statistics, Innovative vs. non-innovative firms

Variable	Obs	Mean	Std. Dev.	Min	Max
All					
Firm empl	4788	158.02	740.28	1	31830
Firm age	4788	21.40	18.57	1	253
Reg. urban	4788	0.34	0.47	0	1
No innovation only					
Firm empl	2613	102.98	240.23	1	4159
Firm age	2613	20.70	17.31	1	143
Reg. urban	2613	0.33	0.47	0	1
Innovation only					
Firm empl	2175	224.41	1063.83	1	31830
Firm age	2175	22.24	19.94	1	253
Reg. urban	2175	0.36	0.48	0	1

The analysis of differences may show a number of similarities and differences between the green innovators and non-green innovators. However, the differences may be caused by other factors such as the size differences of the firms in the two groups. To eliminate these types of effects we take a second step in the data analyses where we apply a propensity score matching of firms. That is we pair each of our green innovators with a non-green innovator with the same structural characteristic (size, age, location).

This procedure may reveal more about the true differences between the two types of firms, not just their characteristics, also their behavior. In the third step of analyses we are also interested in to what extent these differences matter. In other words, as stipulated in proposition 3, are they linked to the performance of firms and if so, in what way are they linked? We operationalize performance in this context as innovative performance and take the share of innovative products in total turnover as our dependent variable, and regress this on a number of independent variables and controls.

3.2. Qualitative analyses

On the qualitative portion of this paper, we present a single case study, which has the purpose of exploring the underlying rationale behind our aggregate findings, by providing the experience of an individual firm (Yin, 2003). The case brings more concreteness to the discussion of collaboration activities in entrepreneurial green firms. Moreover, the case aims at capturing some elements of collaboration activities that have an inherent longitudinal character, which cannot be dealt with by our cross-sectional survey data.

In the domain of green firms in renewable energy, we investigate a company active in the offshore wind power, namely Universal Foundation A/S. Three interviews were conducted with people involved at different functions, as shown in table 2 and whose engagement started at different stages of the development of the company. Thus, the respondents were well-informed of the activities throughout the whole life span of the firm. This is underlined by the fact that the firm is relatively small, about 20 employees, therefore all managers had the full knowledge on with whom they collaborated and why. Additionally, the analysis of archival data, such as firm documents and news concerning the company, also provided the necessary sources for complementing the interviews, and triangulating data. This case study assumes a descriptive character, and aims at portraying the role of different collaboration activities and partners, at different stages throughout the development of the firm.

Table 2 – Interviews conducted for case study

Position		**Duration**	**Date**
Head of Design.	-	45 minutes	April/2015
Member of the board of directors.	Director of the faculty of Engineering, Aalborg University.	55 minutes	May/2015
Entrepreneur, shareholder, member of the board of directors.	Professor, Head of Offshore Foundation and Geotechnical Engineering, Aalborg University.	90 minutes	May/2015
Entrepreneur, shareholder, technology director.	-	60 minutes	June/2015

The qualitative and quantitative parts of this paper function as complements to one another, with the purpose of depicting the phenomena more thoroughly. Hence, whereas the quantitative studies paint the general picture, our qualitative studies provide a closer depiction of some of the underlying explanations, and it contributes to a deeper understanding of some of the potentially non-linear dynamics in how and why green innovators collaborate with external partners in different phases of developments of firms.

4 Empirical analysis, quantitative analysis

4.1. Frequency analyses: Examining propositions 1 and 2

The first of our propositions speculated if green and non-green innovators are different in their propensity to collaborate with external partners. In addition to the tendency for collaboration we list in table 3 the structural characteristics of the two groups as well as the different types of collaboration partners.

Table 3: Descriptive statistics: RE vs. non-RE innovators

Variable	Obs	Mean	Std. Dev.	Min	Max
Non-RE innovators					
Firm age	1109	20.44	19.49	1	253
Firm empl.	1043	114.67	307.61	1	5450
Reg. urban	1109	0.36	0.48	0	1

R&D applied %	556	18.36	30.14	0	100
R&D dev. %	556	50.46	43.59	0	100
R&D basic %	556	2.99	10.04	0	80
Inno process	1109	0.59	0.49	0	1
R&D per empl.	1043	98.91	274.07	0	3230
Cap int	1109	0.44	0.50	0	1
Cap ext	1109	0.23	0.42	0	1
Coop div	1109	0.10	0.19	0	1
Coop up	1109	0.24	0.42	0	1
Coop horiz	1109	0.14	0.35	0	1
Coop down	1109	0.20	0.40	0	1
RE innovators					
Firm age	462	24.58	20.01	1	105
Firm empl.	439	251.15	671.21	1	6671
Reg. urban	462	0.32	0.47	0	1
R&D applied %	283	21.25	28.51	0	100
R&D dev. %	283	55.74	39.55	0	100
R&D basic %	283	2.86	7.99	0	70
Inno process	462	0.67	0.47	0	1
R&D per empl.	439	95.03	417.13	0	6254
Cap int	462	0.56	0.50	0	1
Cap ext	462	0.34	0.47	0	1
Coop div	462	0.19	0.26	0	1
Coop up	462	0.42	0.49	0	1
Coop horiz	462	0.28	0.45	0	1
Coop down	462	0.34	0.47	0	1

The first step in our data analyses is to compare frequencies in the two groups of firms, green innovators and non-green innovators. In figure 3 above, we provide statistics on basic firm characteristics available for all surveyed firms, where we compare firms engaged in innovation activities with their non-innovative counterparts.Innovative firms, accounting for about 45% of all firms in the sample, tend to be bigger in terms of employees, slightly older and located in urban areas. On average, RE innovators appear to be slightly (~4 years) older, and employing about twice the number of employees. In line with De Marchi (2012), RE firms show substantially higher cooperation heterogeneity, measured in the number of actor groups they cooperate with in their innovation activities. While RE firms generally cooperate more often with a more diverse set of actors, their cooperation pattern roughly matches the ones of non-RE innovators, as illustrated in figure 1.

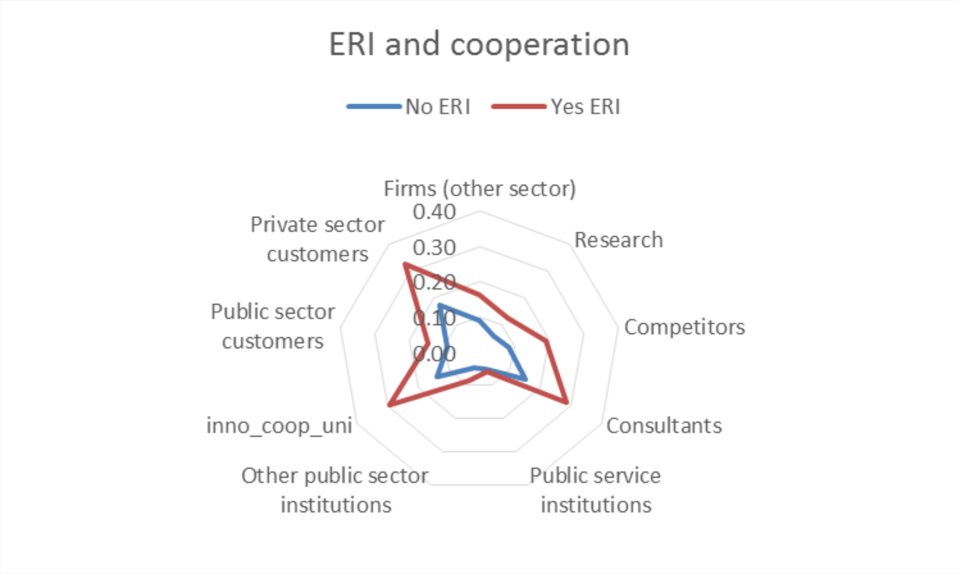

Figure 1: Cooperation pattern by type of actors, RE (red) vs non-RE innovators (blue)

While they about twice as often cooperate with particular actors, the only divergence of this pattern can be found in the cooperation with public service institutions, which is only slightly higher for RE innovators.

In the second step we are particularly interested in different cooperation pattern and diversity. To focus on this difference, we decided to compare only RE and non-RE firms similar in their other characteristics. Therefore we employ a propensity-score procedure, where we matched every RE innovator with an non-RE counterpart similar in number of employees, age, R&D expenses per employee, as well as with the same industry affiliation and regional location. Consequently, our final dataset contains an almost equal number of firms engaged in RE-related and non-RE innovation, similar in the above-mentioned characteristics. We label a firm as cooperating upstream (Coop up) if it indicates to interact with consultants and other private business service, research or public sector institutions. Similarly horizontal cooperation (Coop horiz) is understood as the interaction with competitors or firms from other sectors, and downstream cooperation (Coop down) as interaction with private or public sector customers. Furthermore, we are interested in capabilities a firm might utilize to innovate, which could be internal or external. We label a firm as possessing internal innovation capabilities (Cap int) if it has either an own R&D department or other units engaged in R&D, has filed a patent application or employed researchers holding a PhD degree in the 2011-2013 period. External capabilities (Cap ext) are characterized by firms purchasing R&D or patents in that period. This distinction is relevant because it separates organic capability build-up and the internalization of capabilities originated elsewhere. Although the capabilities of firms are complex constructs embedding several intangible elements, we consider this is appropriate for capturing them in a quantifiable perspective.

Table 4, after matching RE firms with non-RE counterparts of similar size, age, innovation expenses etc. show the differences between the two groups of firms.

Table 4: Descriptive statistics: RE vs. non-RE innovators (PSM)

Variable	Obs	Mean	Obs	Mean
	Non-RE		RE	
Firm age	439	26.71298	439	25.81093
Firm empl.	439	226.5626	439	251.1458
Reg. urban	439	0.330296	439	0.339408
R&D applied %	242	17.53719	266	19.88722
R&D dev. %	242	58.16116	266	56.14286
R&D basic %	242	3.640496	266	2.522556
Inno process	439	0.587699	439	0.667426

R&D per empl.	439	68.40608	439	95.02549
Cap int	439	0.507973	439	0.553531
Cap ext	439	0.287016	439	0.33713
Coop div	439	0.114908	439	0.183751
Coop up	439	0.287016	439	0.414579
Coop horiz	439	0.148064	439	0.277904
Coop down	439	0.261959	439	0.341686
coop firm	439	0.095672	439	0.161731
coop res	439	0.059226	439	0.118451
coop comp	439	0.093394	439	0.189066
coop cons	439	0.182232	439	0.284738
coop pubs	439	0.05467	439	0.061503
coop pubo	439	0.045558	439	0.084283
coop uni	439	0.173121	439	0.280182
coop pubc	439	0.088838	439	0.148064
coop cus	439	0.241458	439	0.32574

4.2. Collaboration and performance: Examining proposition 3

In proposition three we posit that it is likely that there are differences in how input factors links to performance in green and non-green firms. To test this we proceed with a regression analysis linking innovation intensity to a number of input factors and controls.

4.3.1 Dependent variable

Our dependent variable of main interest is the firm's share of turnover of new products (at least new to the firm) in 2013.

4.3.2 Independent variables

As argued before, we expect the pattern through which a firm connects and interacts with other institutions to positively affect their innovation performance. Generally, it can be assumed that a broader set of cooperation partners will lead to access to a higher amount, as well as more diverse external knowledge, thereby making the firm more likely to create novel products. We operationalize the degree of cooperation diversity (*Coop div*) as a measure indicating the diversity of other actors and institutions a firm cooperates with, which takes a value of zero in case of no cooperation activity and 1 for cooperation with all possible groups of actors.[2] Besides the general diversity, also the structure of cooperation networks matter.

Contractor and Lorange (2002) propose that networks may be horizontal or vertical. Laursen and Salter (2006) propose that firms source knowledge 'upstream' in particular cases and in other cases the sources that are closer to the market are more relevant. We divide collaboration partners according to their type in these dimensions and detect collaboration patterns along this typology. The more precise explanation is provided in relation to table 4.

[2] The CIS data explicitly asks if the firm cooperates with (1.) competitors, (2.) firms from other sectors, (3.) consultants and other private business service, (4.) research institutions, (5.) public service institutions, (6.) other public sector institutions, (7.) public sector customers, (8.) private sector customers.

4.3.3 Control variables

We further control for the firms' age (age) and size measured by the number of employees (empl), where both variables enter the regressions in their natural logarithm. Firms in industrialized urban regions are generally said to be more innovative than the ones in rural areas (Storper and Venables, 2004), so we also control for if the firm is located in one of the more densely populated regions of Denmark, namely the larger Copenhagen area as well as East Jutland. Assuming some direct relation between innovation input and output, we also control for the firms expenditure in R&D and other innovation activities relative to its' number of employees (R&D applied %). Yet, not only the amount but also the direction of innovation and R&D activities might matter for a firm's innovation performance. Thus, we also include variables measuring the amount of R&D effort allocated to basic (R&D basic %) or applied (R&D app. %) research, and development (R&D dev. %).

4.3.4 Model setup

In the CIS survey structure, only firms that initially indicate to be engaged in R&D or other innovation activities are asked the full set of questions. To control for possible bias arising from the exclusion of non-innovative firms, we apply a standard two-stage Heckman selection model (Heckman, 1979), where we first fit a logit model estimating if the firm accounts for innovation activity, and insert the predicted inverse mills ratio in the 2^{nd} stage model. In the first stage, the probability to be engaged in innovation activity is calculated as a function of the variables available for all firms, which are their number of employees, turnover, age, legal form, industry and region.

Following a comparative approach, we run the same model, including all independent and control variables first for the whole sample (i.), and then separately for the subsample on non-RE (ii.) and RE innovators.

Table 5 presents the results of the second stage of the OLS regression model adjusted for endogenous selection, with the firm's share of turnover in new products as dependent variable, serving as a measurement for innovation performance. Surprisingly, most of our control variables show no significant effect, neither for RE nor non-RE firms. While literature usually suggests either small and young or mature large firms to be the main carrier of innovation, we do not find such age and size effects in our sample. Even more surprising, a firm's relative innovation and R&D expenditures (*R&D per empl*) in none of the models show a significant effect, questioning a linear relationship between innovation input and output (hypothesis 3). Only the variable indicating that a firm is also engaged in process innovation (*inno process*) appears to be significant at a 1% level in explaining a firm's innovation performance, suggesting a duality between product and process innovation.

Table 5: 2nd stage OLS regression. DV: Share of new products in firm's turnover

	all (i.)	Non-RE (ii.)	RE (iii.)
Reg. urban	-2.13	-0.16	-7.19
	(3.80)	(5.21)	(5.57)
Age_{ln}	-3.65	-7.42	-2.26
	(2.71)	(4.10)	(3.70)
$Empl_{ln}$	0.06	2.79	-2.14
	(1.66)	(2.40)	(2.41)
inno process	16.20***	16.04**	21.15***
	(3.81)	(5.40)	(5.56)
R&D per empl	0.00	0.02	0.01
	(0.01)	(0.02)	(0.01)
R&D applied %	0.11	-0.09	0.262*
	(0.08)	(0.11)	(0.11)
R&D dev. %	0.10	0.05	0.16
	(0.06)	(0.09)	(0.08)
R&D basic %	-0.02	-0.40	0.59
	(0.20)	(0.24)	(0.33)

RE inno	-0.14		
	(3.64)		
Coop div	-169.2**	-123.80	-167.3*
	(57.92)	(90.41)	(81.08)
Coop div^2	126.8**	57.09	135.9*
	(46.74)	(87.04)	(62.29)
Cap int	4.87	32.32*	-19.80
	(8.51)	(12.67)	(11.78)
Cap ext	4.81	17.40**	-5.49
	(4.04)	(5.82)	(5.86)
Coop up	10.93	1.42	8.97
	(8.28)	(12.26)	(11.78)
Coop horiz	20.17**	22.27*	12.14
	(6.99)	(9.70)	(10.13)
Coop down	20.65**	10.80	21.22*
	(7.83)	(12.10)	(10.48)
coop inno * age	0.01	0.07	0.00
	(0.02)	(0.04)	(0.02)
mills	4.19	29.64	-39.98
	(14.19)	(19.01)	(23.02)
N	508	242	266
R^2	0.09	0.23	0.13

*Standard errors in parenthesis. *, **, *** indicate significance on 10%, 5% and 1* level.

When turning to our independent variables of interest, we surprisingly find cooperation diversity to have a strong negative effect, which is more pronounced and shows significance at 10% level for RE innovators. Since we, as suggested in proposition 3, not necessarily expect the relationship between cooperation diversity and performance to be a linear one, we also introduced a squared version of the innovation diversity variable (*Coop div^2*) which indeed turns out to be positive and significant at least on 10% level for RE innovators. This indicates the relationship between cooperation diversity and innovation performance to take the form of an inverse U-shape with an optimum. The question yet remains if this finding captures a tension between diversity and fragmentation of cooperation partners, or is more related to changing cooperation pattern through the product-life cycle. As already discussed, it might very well be the case that especially in RE, long development times of innovative solutions might cause significant time lags between first research and associated cooperation activities and eventually turnover with the resulting products. Indeed, when looking at the type of cooperation, we see that downstream cooperation associated with final product testing turns out to have a positive impact (at least at 10% level) on innovative performance.

Further, early literature would explain the finding that firms who require diverse knowledge and hence seek that knowledge through external collaboration rather than internal build-up of this knowledge with liabilities of newness (Stinchcombe, 1965) and smallness. Related, the literature on the resource based view of the firm (Barney, 1991) points to that firms compensate for resource constraints stemming from their smallness and newness by collaborating with other small, young firms (Hewlet-Dundee, 2006). Their pooled resources may render adequate capabilities to cope with the challenges of innovating. Hence, Hewlet-Dundee (2006) showed empirically that the ability to innovate in small firms was constrained by lack of partners for collaboration whereas the probability of innovating in large firms remained unaffected (see also Rogers, 2004). To test for this substitution effect of firm's age and associated accumulation of capabilities, and external cooperation, we include an interaction term between the age and cooperation heterogeneity. Yet, in our case we find no significant effect.

4.4. Summary of quantitative analyses

Overall, the results suggest substantial differences between cooperation intensity between RE and non-RE innovators as stipulated in proposition 1. We were not able to confirm proposition 2 as a smaller proportion of non-green innovators collaborate, but when they do, they use the same type of partners. Moreover, we confirmed that there are no linear relationships between inputs and collaboration partners on the one hand and innovation performance on the other hand (as suggested in proposition 3). Rather we found (weak) indications that for RE innovators there is an inverse u-shaped relationship as also suggested by Laursen and Salter (2006). A reason suggested is the often long development times in RE projects, which are in need of different partners at different points of time. The nature of our dependent variable here does not allow us to capture direct effects of cooperation on innovation performance (which is true for most commonly used measures, such as patents etc.), and the cross-sectional nature of our data does not allow to disentangle life-cycle effects. The following case study of an entrepreneurial RE firm aim to shed light especially on the up to now unexplained patterns, in particular the missing longitudinal component of the quantitative analyses.

5 Networks, collaborations and partnerships: A case from the offshore wind industry

5.1. Industry context

Denmark has been a pioneer in developing wind energy facilities, and industries associated with it, both onshore and offshore. This can be observed in terms of the collaborative effort of the private sector in developing the industry, the establishment of research and industry networks, as well as public support to foster wind power (Andersen et al., 2014; DWIA, 2014; Garud & Karnøe, 2003). The sector is also vital to the Danish economy. The Danish wind industry generated a turnover of EUR 11 billion in 2013[3], of which 60% refer to exports (DAMVAD, 2014). There are more than 500 firms dedicated to various areas of the wind industry in Denmark, employing 28 thousand people (DWIA, 2014; DAMVAD, 2014).

The Danish wind industry developed by employing an approach termed bricolage (Garud & Karnøe, 2003). The industry emerged bottom-up, by means of collaboration of diverse actors. The Danish approach was based on low-technology knowledge bases and small-scale craft capabilities, such as carpentry and machinery (Andersen et al., 2014; Garud & Karnøe, 2003). The technologies used today in the sector emerged by means of collaboration networks among private actors, as well as with the support of research centres and universities, (Garud & Karnøe, 2003). Thus, collaboration capabilities and networks have been at the heart of the industry development for several decades.

With the expansion of technological possibilities, wind farms started to be placed offshore in the 1980s, although only in the early 2000s they began to become more widespread (Andersen et al., 2014). Together with the advantages of placing wind turbines offshore came several challenges. Two of these challenges were getting the cost structure right, another achieving more standardization and efficiency in the supply chain.

5.2. Company and innovation context

Universal Foundation A/S is a company that offers an innovative solution for the substructures that support wind turbines in offshore parks. Substructures, i.e. foundations, are the construction supports that are installed on the seabed, and upon which the actual wind turbine is set up. Foundations play a key role in this industry for several reasons.The complexity of civil works account for an essential difference between onshore and offshore (EWEA, 2011). Things such as the maritime environment, conditions of the seabed soil and logistics present a superior technical challenge for offshore wind in relation to the traditional onshore installations. This is of course reflected in costs, as in offshore parks, from 20% to 30% of the total capital costs can be attributed to the supply and installation of substructures (EWEA, 2011). There are different activities to be carried out in relation to substructures, which require substantially different capabilities. First there is the engineering and design, which includes studies of soil and seabed conditions. Second there is the fabrication of steel structures. Next are logistics and installation. Some firms have businesses in one of these areas, while others have capabilities of performing several. Universal Foundation is focused on engineering and design.

The innovation brought about by Universal Foundation is the use of a technology known as suction buckets. This technology itself is not the innovation, but instead the application to the context of offshore wind substructures, and the complementary improvements and systems that made it technically viable. This is a classic case of new combinations of existing knowledge that result in innovation (Schumpeter, 1934). Appendix shows, in general terms, how the technology works. Still, for the purposes covered by this paper, it suffices to say that the innovation presents several advantages to the existing substructures.

[3] Offshore wind accounts for about one third of this turnover (DWIA, 2014).

5.3. The origins

The original, early ownership of Universal Foundation consisted of a shipyard (Ørskov), a steel infrastructure manufacturer (Bladt Industries), a company with expertise in steel design structures (MarCon – owned by Bruno Schakenda), a park developer (ELSAM (currently DONG Energy)), and the company that concentrated the interests of the entrepreneurs as shareholders (Novasion). Each of these partners had 20% shares. The investment from these incumbents was essential, as the wind power sector is competitive and capital intensive. Access to the expertise and networks of these partners also widened the range of partners with whom the infant company could collaborate, extending the competences and resources it could tap into.

Armed with an interesting technology, an innovative product and engaged partners, it was essential for the newly established firm to prove its concept in a commercial context. In order to achieve this, in 2002, a prototype was put up nearshore in Frederikshavn, Denmark, upon which a Vestas V90 3 megawatt turbine was installed. This was one of the largest turbines at that time, and the installation still functions to date. This demonstration project was realized through the competences of different partners, both shareholders and otherwise. For instance, Bladt Industries manufactured the steel structure, Aalborg University was involved with the design and engineering, ELSAM provided the site. The project represented a first proof of the concept, and enabled the monitoring and collection of various types of relevant data concerning the soil, ocean and wind, which contributed not only to the improvement of the product, but also to academic research in the field.

5.4. Collaboration activities and partnerships – firm-university collaboration

The case of Universal Foundation is typical, in the sense that collaboration is intensive and with diverse partners, as suggested by our quantitative analysis. The collaboration partners include the firms that entered the partnership, as explained above, but Aalborg University was another key parther. We focus below on this particular type of collaboration partner.

Since the very beginning Aalborg University has been a key partner to Universal Foundation, not only in the early engineering research, but also in offering complementary competences. In the words of an interviewee at Universal Foundation: *"We use, sometimes, the university capacity as a reviewer on our ways of calculations, but also that feeds back, meaning that the findings that we have here benefits the university, and the new students and then the common knowledge in the business. Actually I do believe that it goes well hand in hand. We would not be here, where we are today, if we hadn't had help from the university, but I also think that the business is benefiting greatly from our findings and the cooperation we have with the university"*.

Another contribution of Aalborg University concerned the support in the period in which some of the shareholders went bankrupt after the 2008 crisis. The University's lawyers were involved in negotiating IPR agreements so that the firm could ensure ownership of its key technology. Moreover, the University actually, unusually, invested as a shareholder, and assisted in searching for another investor when DONG decided to leave the business.

Hence, the cooperation between Universal Foundation and Aalborg University has indeed been intense. In addition to the practical events described above, cooperation is also important in terms of research. To date, seven PhD research projects have been completed in relation to mono-buckets, three are currently ongoing, as well as a number of master level projects. Lars Bo Ibsen, the professor involved since the early research is still a minority shareholder, he is actively involved as a consultant, and serves the board of directors. The Director of the Faculty of Engineering is also a member in the Board of Directors.

5.5. Case discussion

Wind power is one of the most mature RE technologies and, according to some observers, one that potentially can lead a paradigm shift from fossil-fuels to renewables (Jacobsson & Karltorp, 2013; Unruh, 2002; Kaldellis & Kapsali, 2013). Nevertheless, precisely because of this maturity, the actors in the sector are somewhat conservative and risk averse. This attitude, combined with the capital intensive character of the investments in question, and the long-term nature of projects, results in challenges to small players and new entrants.

Our case study clearly point to that the way to overcome this barrier is through collaboration activities. This is in line with our quantitative data, which indicates that there is more diversity in the partners with whom green energy firm collaborate. Small, entrepreneurial, green energy firms depend on partners that control resources which they do not, and have complementary competences that they need in order to grow. Collaboration activities are a central element for capability building in entrepreneurial green companies. In these firms collaboration activities also play a role in increasing their legitimacy in the business and the reliability of the innovations they introduce.

This outlook on collaboration activities is different, for example in large incumbents. These firms have in house a wider array of competences and resources they need, not only for their everyday business, but also for R&D and innovation. Moreover, incumbents have already built a reputation in the sector. This makes them more protective of their knowledge and competences, and keeping them exclusive is a source of competitive advantage. As a result, collaboration to them has a different meaning; it is restricted to fewer partners and in specific situations.

The case also showed that there was a change in the key collaboration partners throughout the development of the firm. In the very beginning, the university played a crucial role, providing access to specialists in diverse knowledge bases (geotechnical, construction, materials, robotics etc.), offering a platform for searching for investors, negotiating deals concerning patents, to name but a few. As the company evolved and reached a more mature level, other partners became more central. At this point, Universal Foundation is deeply involved with its parent company, and is cultivating close relationships with other firms in the group. Moreover, at this point, the firm had reached a stage where it became central to develop a supply chain capable of delivering the foundations designed by Universal Foundation, as well as working with certifying bodies recognized by the industry.

Despite being fourteen years old it is not yet what could be termed a mature firm, and follows a dynamics that comes closer to a start-up or a young firm. Their innovation still requires validation that will persuade the sector of its viability, and decrease the risks associated to it. This suggests that green entrepreneurial firms, especially in the energy sector, require longer periods to penetrate the market and their revenues are often relatively de-linked from input factors due to the technological, market, and financial uncertainties and the long time span between input factors and output. This observation supports our third proposition that, the relationship between input and output (R&D and market) is weaker or non-linear in green innovators, due to the long time-lags they face.

6. Discussion, conclusions, implications

Based on existing, earlier studies we developed propositions on the collaboration patterns of greenagers. In line with a range of other recent studies we found that green, entrepreneurial (here understood as innovative) firms have higher cooperation intensity than other innovative firms that do not have innovations in renewable energy. We ascribed this finding to the systemic character of 'green' innovation and the broader knowledge base in use for taking these innovations through. Earlier studies pointed to that entrepreneurship is particularly important for eco-innovations (Wagner and Llerena, 2011), and from a resource-based view of the firm it can also be argued that to cope with the challenges of entering a scale-intensive and large infrastructure dominated energy sector entrepreneurs need to collaborate to a higher extent.

Based on some of the same arguments around the specific character of green innovations we also expected that the green innovators would display a broader and different range of partner types in their pattern of external collaboration. In our initial analyses we indeed found higher diversity in collaboration partners in RE innovators but we suspected that some of the effects on collaboration patterns we found in frequency analyses were driven by intermediating factors like differences in size and age. Consequently we did a propensity match scoring analysis that matched each observation in our dataset with a counterpart with similar characteristics. In this manner we were better able to isolate behavioral differences from the characteristics.

We found, contrary to expectations, overall the same patterns in the use of types of partners in the two groups of firms. However, some differences came up regarding the collaboration with 'upstream' sources, for example universities, where green innovators seemed more prone to engage in collaboration with these.

Related, we also proposed that it would probably be difficult to correlate input factors with output factors in green firms. The character of green, entrepreneurial firms and the industry they operate in may explain why the business model of these firms does not provide instant economic output, as was also displayed both in our regression analyses and case study.

The limitations of quantitative analyses are well-known and naturally apply to our case as well. We may be able to reveal correlations whereas causalities are trickier to determine with quantitative analyses. Hence, our quantitative studies were unable to reveal the direction of causality regarding if firms who are well networked leverage that for better innovative performance, or they initially are innovative and subsequently use networks for carrying the full innovation process through. Undoubtedly in some cases both mechanisms are in play. To dig deeper into the mechanisms behind the results we supplemented our analysis with a single-case, qualitative study. Our qualitative studies confirmed many of the presumptions we build our design of the quantitative analyses on, and made us more confident in the way propositions and interpretations of results were made. It also illuminated some of the motivations behind collaboration and choices of collaboration partners, something we could only map in our quantitative studies. It therefore provided valuable information on the mechanisms behind our story.

The fact that green, innovating firms seem to be more intensely involved in interaction with outside partners have implications for green innovators and for policy. For green innovators we point to the need for these firms to actively engage in networks to obtain information on which partners for innovation are the most appropriate to broaden their knowledge base, and access a variety of capabilities and resources that are indispensable to the organization. This, however, requires search for finding and configuring the networks and it requires skills to manage network participation in a productive manner. Therefore, we propose that skills in 'interpreneurship' should be enhanced in greenagers and other small firms. This is worth considering in relation to policies but also in connection with the curriculum of business schools. Both in policies generally, and in teaching business students it is often emphasized how important networking is. However, it is rarely explained how to do so. Nevertheless, network search, creation, management is nowadays a discipline in itself but rarely unfolded in an explicit manner.

We furthermore propose that modern innovation policies, which are today often aimed at correcting systemic failures rather than market failures, should be more intensely geared towards facilitating the creation of links between partners in green innovation processes. We showed that the green innovators already collaborate relatively more but also that this is needed to get green innovations to the market. Our results may also be read as indicating that policies for enhancing links between firms engaged in green innovations need not be different than other policies, even though special policies tailored to the context of green entrepreneurship may fulfill several other meaningful goals. This is implied by the fact that types of collaboration partners are roughly the same among the two groups of firms analyzed. Finally, policy should recognize the time lag and non-linear relationship between input and output factors in green innovation. This complicates evaluation of policies and failure to show effects of policies in such evaluations may mistakenly lead to abandoning policies, which in turn may harm the greenagers.

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Appendix