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Branching and path development in the wind energy industry

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Abstract

The present paper analyses industrial evolution, taking the industry life cycle as the theoretical point of departure. New industries often grow out of existing, related industries. Offshore wind energy is an example of such an industry, which has branched out of the traditional (onshore) wind energy industry, but is increasingly facing challenges which push offshore wind energy further away from its starting point as a market diversification for onshore wind energy firms. The analysis illustrates how the development path of the offshore wind energy industry deviates from the generic model of industry life cycle development in one important aspect. Contrary to the general perception that new industries grow out of existing ones when these existing industries are in a phase of decline, offshore wind energy is branching out of the traditional wind energy industry while this is still in a growth phase. The result is a co-existence of two related industries that are at different stages of their life cycles. Firms therefore experience increasing strategic complexity regarding which opportunities to pursue. The strategic complexity is reflected in a relatively high degree of inter-firm variety within the emerging offshore wind energy industry, which manifests itself into three main – but not necessarily stable - types of firm perceptions regarding and behaviour in relation to the new business area that offshore wind energy comprises. The empirical findings of the paper add to the existing theoretical discourse on industrial evolution by stressing the need to focus more on how individual firm strategies may create a much more complex evolutionary pattern than the general model of industry life cycles prescribes.

1. Introduction

The idea of co-evolution of firms and industries has assumed many disguises in the fields of political economy, innovation economics, and evolutionary theory. At the macro level, the concept of industrial districts (Marshall, 1890) has focused research on the co-existence of accessible pools of labour, knowledge and industrial inputs, to some extent assisted by industrial policy and financial resources (Pyke, Becattini & Sengenberger, 1990; Dahmén, 1988). Following the Schumpeterian idea of co-evolving patterns of innovation which alter the economic system (Schumpeter, 1934) and stages of development within the national economy (List, 1841), co-evolution has been targeted in terms of regional (Asheim & Gertler, 2005), and national (Lundvall, 1992; Nelson, 1993) systems of innovation, emphasizing the role of institutional dynamics and processes of learning. At the micro level, the focus on co-evolution has been inspired by the notion that the economic efficiency of the market mechanism is enhanced by various ways of organizing the market, e.g. in terms of complementary activities (Coase, 1937; Richardson, 1972; Williamson, 1975), networks (Håkansson, 1987), and the co-existence of competition and cooperation, i.e. coopetition (Brandenburger & Nalebuff, 1996; Bengtsson & Kock, 2000; 2014).

The present paper primarily operates at the meso level. Taking the point of departure in current developments of the industrial life cycle approach (Abernathy & Utterback, 1978; Suárez & Utterback, 1995; Klepper, 1997; Ter Wal & Boschma, 2011) we seek to advance the understanding and conceptualization of industrial evolution through branching. The analysis is based on a study of the offshore wind energy industry, which in certain aspects deviates from the generic model of industry life cycle development and thereby points to some lines of development which add to the existing theoretical discourse.

As noted by Ter Wal and Boschma (2011), there is increasing evidence that new industries do not emerge out of the blue, but tend to grow out of existing, related industries. However, it is still the general perception that new industries grow out of existing ones when these existing industries are in a phase of decline. The new industry thus 'replaces' an old industry. But in reality this is not always the case, a new industry can emerge out of an existing industry that is still in a growth phase, thus resulting in two related industries existing side by side at different stages of their life cycle. The co-existence of two related industries represents two different paths of opportunity for firms to pursue, increasing strategic complexity.

A further inquiry into industry branching may increase our understanding of industry evolution and widen our perspective on what may spur the emergence of a new industry. An analysis of new industry emergence is heavily dependent on the definition of an industry. As argued by Niosi (2000), evolutionary branching through rapid innovation and product variation can blur the frontiers of industries. In consequence we infer that, not least in empirical analyses, it can be difficult to draw the line between within-industry variation and the emergence of a new industry. The argument in the present paper is that what starts out as a market diversification through branching-out may over time face technological challenges that push the branched-out activities further away from their starting point, eventually reaching a stage where the technological solutions and market opportunities are so distinctively different from the ones characterizing the 'parent industry' that a new industry – or, from the firms' perspective, a distinct business area - has emerged.

Firms within an industry are heterogeneous; having different backgrounds and capabilities (Porac et al., 1995) which, at least partly, determine the individual firms' positions in trade and knowledge networks within the industry. This heterogeneity influences the evolutionary path of the industry, but at the same time the degree of heterogeneity is assumed to change over the life-cycle. However, the patterns of evolution over the life-cycle are likely to depend on the processes leading to the emergence of an industry, and on the specific characteristics of the firms within the industry (Avnimelech & Teubal, 2006).

Therefore, the present paper studies how the interplay between firms' different starting points, capabilities, and relative positions to other firms may shape the early development of an industry. Specifically we look at an industry that has emerged from branching-out activities from an existing industry which has not yet reached the stage of technological disruption and industrial decline.

The paper is structured as follows: Section 2 presents the theoretical starting point of the analysis and sets the scene for section 3, which introduces the case story that comprises the empirical foundation of the paper. Section 4 presents the data that are used in the clustering analysis in section 5. Following the presentation of the results in section 6, the concluding section 7 discusses the results and identifies avenues for further research.

2. Theoretical foundation

The economic analysis of the co-evolution of firms and industries can be perceived as mainly founded on a realist approach (Kwan & Tsang, 1999; Hausman, 1989). The realist approach implies that causative processes must be understood as the interplay between contingencies which do not lend themselves to scientific prediction, but only to the discovery of regularities, especially in the case of open systems (Bhaskar, 1975/2008; Sayer, 2000). The objective of research is to unveil the salient structure which underlies phenomena and events, and the mechanisms which translate the underlying structure into the phenomena and events studied. However, the possibility of prediction does not present itself, because the interplaying causalities vary from time to time and from case to case – and this would be the case, even if we were able to master the overwhelming degree of complexity and number of causalities creating real-life phenomena and events. In essence, what this implies for studying the co-evolution of firms and industries is that no finite causalities can be identified, but that scholarly explanations instead must rely on regularities to be interpreted within the economic, technological and institutional setting in which they occur.

The necessity of creating interpretive schemes is clearly visible in the various lines of theorizing on the co-evolution of firms and industries, whichever the theoretical tradition might be. The inspiration from Marshallian economics (Marshall, 1890) which has spurred analysis of the interplay between pools of labour, knowledge, industrial inputs, financial resources and industrial policy, has led to concepts like industrial districts (Pyke, Becattini & Sengenberger, 1990) and development blocks (Dahmén, 1988), both of which codify certain types of regularities within particular settings. These settings are analysed in terms of cases, including regional and national circumstances and institutional conditions, thus exemplifying the kind of contingent reasoning which is necessary to grasp the underlying structure of the phenomena and events studied. Similarly, the concepts of regional (Asheim & Gertler, 2005) and national (Lundvall, 1992; Nelson, 1993) systems of innovation are strong interpretive schemes presenting regularities of the co-evolution of firms and industries within specific settings emphasizing institutional dynamics and processes of learning. In this line of reasoning, co-evolution is system-contextual, and the analysis is based on the identification of regularities which can be found across cases and systems, but nevertheless vary according to the specific economic, technological and institutional circumstances in which they operate.

Often, the creation of interpretive schemes relies on identifying general cases which may capture different types of real-life phenomena and cases. For instance, the work on the co-existence of competition and cooperation, i.e. coopetition (Brandenburger & Nalebuff, 1996; Bengtsson & Kock, 2000, 2014) develops general cases based on specific case studies which reveal different types of balances between competition and cooperation. These types of balances are not attributable to specific industries or types of firms, but may be found across industries and groups of firms, depending on the actors involved and the present economic, technological and institutional setting. A similar vein is present in the work by Niosi on the evolution of science-based industries (Niosi, 2000) which leads to the identification of four general cases according to which an industry is initially concentrated or dispersed and subsequently becomes or remains concentrated or dispersed. These four stylized cases appear to cover a number of different science-based industries, where the position of each industry depends on the evolutionary interplay between innovation, variation and institutional structures. As this interplay is dynamic and varies over time, the present position of an industry may change as new balances between the forces of innovation, variation and institutions develop.

The realist approach implies that deterministic patterns of development do not enter the analytical scheme. Regularities of development occur, but they are not signs of one uniform type of development. Thus, interpretive schemes must not lead the scholar to conclude that deterministic patterns prevail. This is a strong requirement, as interpretive schemes are highly seductive, especially when they operate at high levels of aggregation and try to cover long periods of time. An example of this is the notion of techno-economic paradigms (Freeman & Perez, 1988; Perez, 2004), which portray long-term industrial and socioeconomic development as transitions across dominant modes of economic development and industrial activities. Even though the stylized facts of techno-economic paradigms are derived retrospectively, it is tempting to interpret the stylized facts as some sort of semi-automatic causality which transcend into the future, especially when they are combined with long cyclical waves of economic activity (as they often are). Furthermore, even though the intricate working of the mechanisms identified in the various techno-economic paradigms are analysed in terms of varieties of institutional frameworks, the stylized facts are assumed to generally operate across institutional settings. In effect, caution is warranted in order to avoid falling into a deterministic trap.

The danger of a deterministic trap is very much present in the case of the famous S-curve, which can be applied on all phenomena that are assumed to progress from an embryonic state to growth and eventually decline (and probably death). For instance, the product life cycle, which primarily was developed during early post-war research on the interplay between market diffusion and strategy (Rogers, 1962; Levitt, 1965), and on patterns of international trade (Vernon, 1966; Hufbauer, 1966), have been used to predict the market position of products and develop accommodating strategies, thus becoming a self-fulfilling prophecy rather than a retrospective analysis (Foster, 1986; McGahan, 2000). Similarly, the original industry life cycle model (Abernathy & Utterback, 1978) has been interpreted as a general prediction of how industries come in and out of existence, although variation occurs across a large number of cases (Klepper, 1997).

In conclusion, the analysis of the co-evolution of firms and industries must rely on the discovery of regularities which are understood as causative, but not deterministic, interrelations between dynamic forces operating within specific economic, technological and institutional frames. The understanding of these regularities require that interpretive schemes are applied, e.g. in the form of stylized facts, archetypes of strategic behaviour, certain market mechanisms, institutional processes, and phases of development. Finally, the process of co-evolving must be understood as contingent and system-specific.

The industry life cycle perspective

Within the realist tradition, the present paper applies the industry life cycle perspective as an interpretive scheme for understanding the development of the Danish offshore wind energy industry. It does so by applying the concept of branching-out (Frenken & Boschma, 2007) in order to understand how clusters of industrial activities lead to the development of a new industry, and interprets branching-out in terms of the classic idea that the emergence of dominant designs is an important driver of industry evolution (Suárez & Utterback, 1995). It is argued that branching-out depends on the prior experience, cognitive frames, and interactions of the actors involved (Kaplan & Tripsas, 2008; Benner & Tripsas, 2012), and that the industry in question develops through intermediating change, i.e. "architectural innovation that originates within established relationships" (McGahan, 2000, p.4), which may be conceptualized in terms of phases of development.

The analysis of industry life cycles is a well-established tradition and goes way back before the advent of the industry life cycle model proposed by Abernathy & Utterback (1978), which is often mentioned as the origin of the S-curve industry life cycle model. Besides the industrial district idea, originally sketched by Marshall (1890), the Schumpeterian analysis of the UK railway evolution (Schumpeter, 1934) and Stigler's analysis of how firms specialize over time as industries mature (Stigler, 1951) are examples of prominent industry life cycle interpretive schemes. While Schumpeter focused on how business cycles are fuelled by irreversible swarms of innovations, and Stigler was preoccupied with the relationship between market expansion and inter-firm division of labour, Abernathy & Utterback (1978) aimed at explaining how market forces yield to technology change caused by industrial actors as a driver of industrial development. Looking into such cases as rayon, semiconductors, aircraft, light bulbs, and automobiles, they proposed that industry evolution depends on the reduction of technological uncertainty.

At the early stage of the emergence of an industry, the actors are faced with both target uncertainty and technical uncertainty, i.e. uncertainty regarding what innovative efforts are actually aiming at, and how different solutions can be brought to work. This is a period of transition where innovation is as much user-driven as producer-driven, and where expectations at the demand and supply sides are not coinciding. However, through experimentation and trial-and-error, demand and supply side expectations tend to coincide, and a dominant product design is emerging. This partly stimulates and partly is stimulated by R&D investment, i.e. a dialectical relationship between the emergence of a dominant design and the dynamics of R&D efforts exist. The acceptance of the dominant product design is heavily influenced by significant process innovation, creating productivity growth which leads to reduced cost and reduction of market prices. As the industry matures, specialization among firms increases, and process innovation occurs increasingly as product innovations by suppliers rather than process innovation by producers. Standardization of products and processes becomes dominant and is accompanied by increasing formalization in decision making and governance.[1]

The balance between first and second mover advantages is a recurrent issue in industry life cycle analyses, especially because the industrial pattern seems to involve a process of shake-out where the industry tends toward oligopoly in the later stages of its development. In consequence, the question arises when it is most opportune to enter the industry. Testing data from the automobile, typewriter, transistor, electronic calculator, television, and picture tube industries, Suárez & Utterback (1995) find that firms entering an industry before a dominant design has emerged tend to be more successful than firms entering after the emergence of a dominant design. However, the results are ambiguous. Klepper (1997) employs a more subtle approach, focusing on entries and shake-outs along the entire life cycle and not only employing a pre-dominant design and a post-dominant design division, and finds that chances of survival is strongly associated with early entry, but that firms entering late also have comparatively high chances of survival. Shake-out seems to be more likely for firms entering in between. The main reason might be that early entrants are those who shape the industry and thus enjoy lasting learning curve effects, while late entrants are especially targeting niche positions which appear as available spots as specialization among firms develop.

Perhaps the issue is not so much about first and second mover advantages, as it is about competencies and prior experiences. Focusing on how radio producers enter the television receiver industry in the US, Klepper & Simons (2000) find that entrants with prior relevant experience are more likely to survive than entrants without prior relevant experience, and that they, furthermore, are more likely to be early entrants. In effect, early entrants are predominantly firms with relevant technological experience. Relevant technological experience is important for the development of R&D capabilities, and as R&D capabilities are important drivers for the ability of the firm to participate in the emergence of a dominant design, firms with relevant technological experience are more likely to assume strong positions at the market. Since R&D capabilities also are influenced by investments in R&D capacity, firm size (implying investment capacity) seems to be another important driver for survival.

Benner & Tripsas (2012) elaborate on the importance of prior experience by associating prior industry affiliation with the type of product innovation choices which firms make as they participate in creating new

[1] Although not referred to directly, but only recommended as further reading, it is, of course, obvious that the work by Utterback & Abernathy (1975) on process and product innovation models is a highly influential source of inspiration for Abernathy & Utterback (1978). Utterback & Abernathy (1975) proposed the now famous model of how product innovation succumbs to process innovation as an industry matures, and validated their proposition by testing the model on the 567 commercially successful innovations from five industries and 120 firms, which had previously been studied by Myers & Marquis (1969) as part of the seminal SAPPHO project. A strong driver for this kind of phasing was arguably the industrial actors' increasing acceptance of specific technological solutions, leading to standardization which eventually causes process innovation to become dominant as cost becomes a strategic driver for market success. This line of reasoning was later rephrased by Suárez & Utterback (1995) as "the dominant design-technological evolution model".

industries. Analysing the digital camera industry, they find a variety of behavioural patterns which can be explained in terms of origin of industry: "…photography firms were more likely to frame a digital camera as an analog camera substitute, consumer electronics firms to frame it as a video system component, and computing firms to frame it as a PC peripheral" (p. 297). They interpret the relationship between behavioural patterns and prior industry affiliation as the outcome of shared beliefs among firms with similar industrial backgrounds, i.e. the shared beliefs frame technological development in a certain way which is consistent across the in-group of firms in question. Apparently, "(c)ommonly held perceptions, expectations, and assumptions become particularly salient when firms enter a highly uncertain emerging industry that incorporates novel technologies with novel uses" (p. 281). However, as time goes by and the industry matures, incumbents tend to develop shared beliefs which diminish the importance of prior industry affiliation. This is, we propose, a cognitive equivalent to the occurrence of a dominant technology-design.

According to Kaplan & Tripsas (2008), the framing of a new industry depends on the development of collective frames created by interactions among the actors within the new industry, including institutions which exert influence on the industry in question. Initially, different actors operate within different technological frames and pursue different technological solutions based on their interpretation of the technological frame in question. However, through interaction the actors gradually approach a joint understanding of which technological problems to solve and how to solve them. Their interpretation of their original technological frames, and the mutual choices they make, will meet both constraints and enablers caused by the technology itself. In consequence, "a collective technological frame co-evolves indirectly with the technology itself through the actions and interactions of actors" (p. 792). As technological development is based on the experiences and decisions which actors make, the occurrence of a dominant design depends on whether or not a collective technological frame is created, and the dominant design will not emerge if a collective technological frame fails to appear.

In a similar vein, Geels (2014) points out that managers in an industry share cultural-cognitive categories and frames, sometimes referred to as 'industry recipe' (Spender, 1989) or 'industry mindset' (Phillips, 1994). In their perspective they constitute the nature of reality, shape interpretations of (pressures and opportunities in) external environments and influence strategic choices and decisions. Rather than prescribing specific lines of actions, cultural-cognitive frames such as industry recipes are shared interpretations that a group of managers within an industry may see as providing a sensible roadmap for what is profitable and relevant and where opportunities and risks are to be found within the industry. At the same time it offers no guidance in how best to appropriate these gains or avoid the risks (Spender, 1989).

The ideas of cultural-cognitive frames and industry recipes are interesting because they add a cognitive element to the industry life cycle model. According to Kaplan & Tripsas (2008), collective frames do not only explain the emergence of continuity associated with a dominant design, but also the occurrence of discontinuities which give rise to new industries. Discontinuity appears as the clash between existing technological frames and new technological frames which open up for new opportunities and solutions. In the view of Kaplan & Tripsas (2008), established firms within an existing industry do not fail to engage in new opportunities only because they are locked-in by previous resource endowments and existing resource dependencies, as argued by e.g. Christensen & Rosenbloom (1995) and Christensen & Bower (1996). Equally important is that they are cognitively trapped within existing technological frames which prevent them from envisioning and recognizing new opportunities.

The idea of technological frames, which adds a cognitive flavour to the life cycle perspective, may be used to explain the phenomenon of evolutionary branching described by Frenken & Boschma (2007). While they apply the concept of branching primarily within the field of economic geography in order to explain the evolution of urban economies, the concept "is sufficiently flexible to be extended such as to become applicable in more specific micro-contexts" (p. 635). The basic reasoning behind the concept of branching is that routines, which are replicated by the setting up of new divisions/subsidiaries, spin-offs, and labour mobility, open up opportunities for new ideas as their spread allows for re-combinations to occur. The reason is that the application of routines is contextual, and in effect a given routine will never be completely applicable in a new setting. Consequently, variety occurs, and diversifications arise even within existing technological paradigms. From the point of view of technological frames, we may interpret branching as gradual discontinuity arising within an existing industry, thus leading to the fermentation of a new industry in which new collective frames may develop as the industry matures.

Elaborating on this line of reasoning, which combines the idea of technological frames with the concept of evolutionary branching, we might argue that the speed by which a new industry emerges depends on the extent to which new frames are being adopted by industrial actors. Industrial actors will differ in their adoption of new frames, depending on their absorptive capacity and the technological and cognitive distance between existing and new frames. In effect, the industrial actors will participate differentially in the creation of the emerging industry, and this kind of variety may be expected to increase over time, as branching implies that the set of technological and market opportunities gradually becomes more diversified. The increasing degree of variation is, actually, in accordance with the previous observation (Klepper, 1997) that early and late entrants tend to survive better than "in-between" movers, because they meet different selective pressures. While early entrants contribute to shape the industry and thus define the kind of selective pressures which will prevail at the market place, "in-between" entrants become subjected to these pressures, while late entrants have the opportunity of mitigating selective pressures by targeting specific parts of the existing variation.

The outcome will be an increasing diversity of technological and economic behaviour across the actors participating in the existing and emerging industry, and, consequently, as the new industry emerges, we might expect to find regularities of behaviour which characterize and differentiate different groups of actors in terms of how they relate to the emerging industry, and how they participate in the creation of the new industry. How we understand these regularities depends on the kind of interpretive scheme employed.

Regularities of behaviour across groups of industrial actors are typically conceptualized in terms of archetypes, clusters, and networks. This is a kind of interpretive scheme which employs the idea of a representative actor who, more or less, captures the average or typical behaviour of a group of actors. Archetypes are well known in research on strategic behaviour, e.g. the Miles & Snow (1978) distinction between reactive and proactive behaviour, and can be applied to industry evolution as exemplified by McGahan (2000) who distinguishes between non-architectural and architectural patterns of industrial development. Clusters are normally conceptualized as firms engaged in industrial activities which constitute a value chain or value network within a spatial dimension (Brusco, 1990; Porter, 2000), e.g. Silicon Valley (Saxenian, 1994) or Emilia-Romagna (Brusco, 1982), while networks are portrayed as relationships between actors organized around cores and peripheries of varies types of economic and social interaction (Burt, 1992; Powell & Grodal, 2005).

However, as argued by Ter Wal & Boschma (2011), industry life cycles are contingent upon the co-evolution of firms which are heterogeneous, even though they belong to the same cluster or network. Inspired by the notion made in Nelson & Winter (1982) that firms differ in terms of capabilities and lines of behaviour, Ter Wal & Boschma (2011) focus on the variety of firms in clusters and network, and they propose a four stage life cycle model (cf. table 1) which takes into account the role of firm behaviour, and the evolution of clusters and networks. The model indicates that the technological regime of an industry becomes increasingly explicit and certain, as firms are locked-in to certain networks and clusters, and that the lock-in phenomenon contributes to creating dominant designs. This kind of strength also becomes the kind of weakness which eventually contributes to the decline of an industry, i.e. "the mature character of an industry in terms of a decline of innovative activity is not merely due to exhaustion of the technological opportunities for further innovation, but it also relates to inertness in patterns of interaction among firms within the industry" (ibid., p.927). In sum, the way in which the industry evolves depends on a dialectical relationship between technological opportunities and interactions among actors situated in economic structures which shape and are shaped by the interactions themselves.

Table 1. A life cycle perspective on the co-evolution of firms, industries, networks and clustering
(Ter Wal & Boschma, 2011)

	Firm	Industry			Network	Clustering
			Technological regime			
	Variety	Number of firms	Tacitness	Uncertainty		
Introductory stage	*High*	*Low*	*High*	*High*	*Unstable*	*No clustering*
Growth stage	*Increasing*	*Increasing*	*High, but decreasing*	*High, but decreasing*	*Towards core-periphery*	*Emergence of clusters*
Maturity stage	*Decreasing*	*Decreasing (shake-out)*	*Low*	*Low*	*Network lock-in*	*Cluster lock-in*
Decline	*Decreasing*	*Decreasing*	*Low*	*Low*	*Dissolving network*	*Disappearing clusters*
Start of a new cycle	*Increasing*	*Low*	*High*	*High*	*Unstable*	*No clustering*

In the following we will adopt the notion that a new industry emerges as branching out takes place, formed by the cognitive frames of industrial actors, of which actors with a close affiliation to the industry in question are more influential regarding the creation of a dominant design than actors with a more distant affiliation. We will expect that the actors engage in networking and exhibit regularities of behaviour, however characterized by differences among actors regarding capabilities and market behaviour.

Regularities of behaviour will be discovered by triangulation, i.e. we combine storytelling and qualitative interviews with quantitative surveys, and, furthermore, subject the quantitative data to a clustering analysis, where we subsequently also analyse differences in network density across the identified groups of firms. In doing so, we will employ the idea of phases in industrial life cycle as an interpretive scheme in order to understand the present status of the industry under scrutiny. Following Ter Wall & Boschma (2011), this will have implications for our analysis: As the industry under scrutiny progresses through the introductory stage we expect an increasing number and variety of firms, which is reflected in a co-existence of different types of collective technological frames.

3. Case story: the branching out of offshore wind energy

Wind power is the world's fastest growing source of energy and the contemporary wind energy industry is globally present. The modern wind energy industry originated in Denmark and it genesis is described in several accounts (Karnøe, 1991; Garud & Karnøe, 2003; Jensen, 2003; Andersen & Drejer, 2008). Several co-constructive events triggered its development in Denmark in the early 1970s. These include a looming energy crisis with high unemployment figures and an active anti-nuclear grass root movement, which tied in with other social movements experimenting with alternative ways of organizing society, including localized energy production (Andersen & Drejer, 2008). Also, natural conditions, such as Denmark being a very windy country and hence an ideal spot for the harvesting of wind energy contributed to this development. Nonetheless, the connection of wind turbines to the electrical grid was initially strongly resisted by central constituents in the Danish energy sector, who foresaw another energy future for Denmark, based on nuclear energy. However, in the eye of the public, the resistance added to a David and Goliath narrative within parts of the Danish grass root movement and, consequently, wind energy gained momentum in the public eye (Andersen & Drejer, 2008).

The emergence of the wind energy industry

The political legitimacy of wind energy increased as the Danish social Democratic Government in 1979 decided to support the construction of wind turbines through the so-called energy package, providing market subsidies to private investors, investing in certified equipment. At this stage, designing a safe, reliable and efficient wind turbine generator and in a way so that it was able to connect to the power grid was central for the technological development. The Risoe research institution – then a world leading research institution in nuclear energy research – was asked to develop test and design facilities in order to support developers of wind turbines in their design and certification efforts. Subsequently a small group of machinery firms suffering from the prolonged economic crisis such as Vestas (the world's largest producer of wind turbines today, then a producer of agricultural equipment) started producing wind turbines on their existing production equipment. Vestas and several other manufacturers followed a process where the design and construction of wind turbines was seen very much as representing a set of problems similar to those they had faced in agricultural machinery (Garud & Karnøe, 2003).

The growth stage of the wind energy industry[2]

With several subsidies from the Danish government for wind energy production, a market for wind turbines began to stabilize in the early eighties as private users started to form guilds and collectively invest in wind energy. Later on this was in the mid-eighties followed by tax subsidies for investment in wind turbines, which also spurred inflow of private capital. Along with this development, the Danish state encouraged state-owned energy companies to invest in wind energy as well. At the same time the state of California began to invest heavily in green energy, resulting in a demand boom for wind turbines.

Consistent with the pattern of evolution seen in several other assembled industries, what followed was a surge of business actors, introducing innovative solutions and a diversity of technologies to the field and gradual scaling-up process of wind turbines in terms of size and capacity. Shifting Danish governments have continued to invest in the development of wind energy capacity and the development of wind energy as an alternative and sustainable source in the energy mix also drew attention from other countries and exports began to increase. See figure 1 for the worldwide development in installed Wind power capacity (in Megawatts).

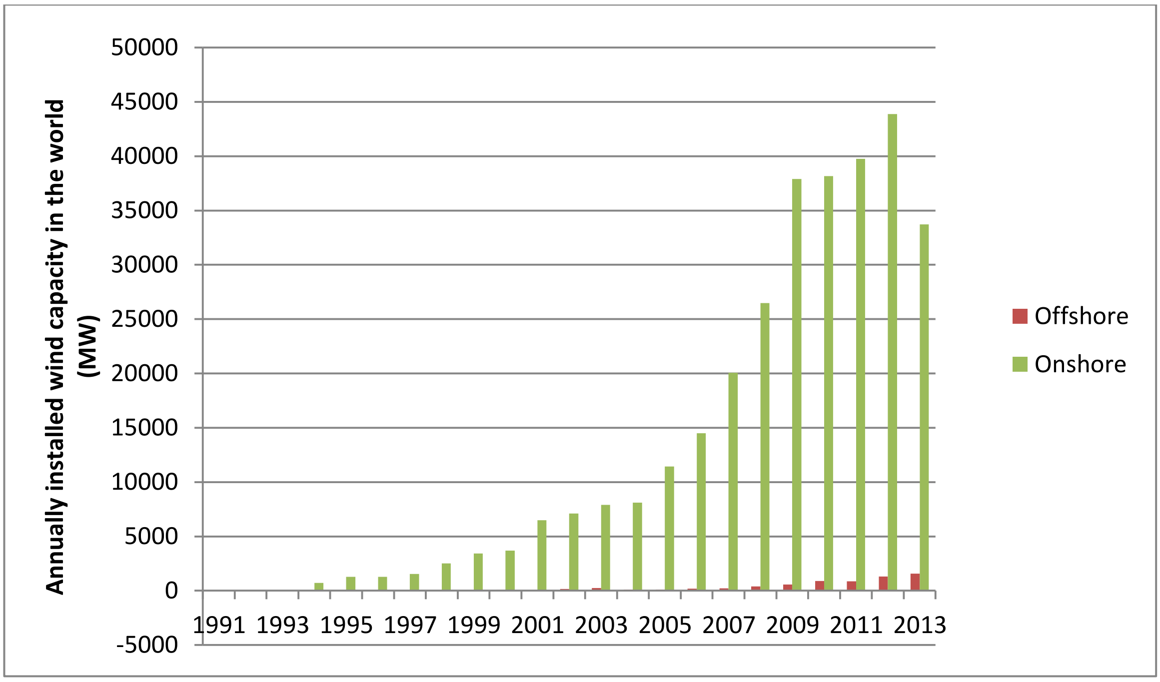

Figure 1. Worldwide annual installed wind power capacity, MW
Own calculations based on EWEA (2014) and GWEC E(2014)

[2] The analysis of industry life cycles is based on an understanding of the cycles being divided into phases on emergence, growth and decline. Growth and decline is often coupled to number of firms or demand. It is, however, an important point that growth rates in e.g. number of firms can be higher in the 'emergent' than in the 'growth' phase because a small numerical increase in an initial small number will lead to a very high growth rate. Therefore we propose that much more attention is also directed towards the importance of the development of the necessary institutional set-up for industries to move from a highly uncertain emergent phase to a growth phase and subsequently to a mature phase.

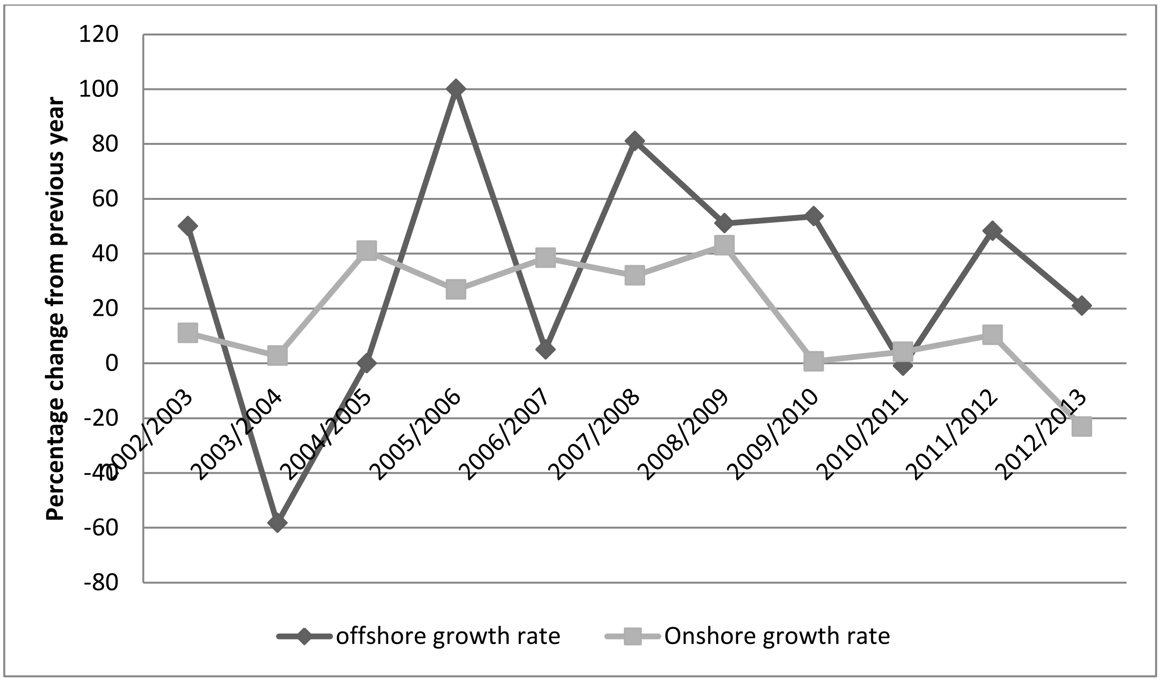

Figure 2. Annual growth rates installed MW,
Own calculations based on EWEA (2014) and GWEC E(2014)

With the growth in market size and in production volume, a clearer and more consistent pattern of market demand began to appear with respect to the technical standards expected from wind turbines, leading to a growing standardization of technical components, such as gears, blades, brakes and yaw systems. It became increasingly recognized among manufacturers that delivery ability, durability of components and turbine production capacity were the main competitive parameters in the industry, in effect forming what in the industry evolution literature has been called a dominant design (Suárez & Utterback, 1994). A dominant design helps enforcing standardization and production economies, reflecting also the exponential growth in the demand for wind turbines shown in figure 1. Today, the main volume driver of the wind industry continues to be the expansion of onshore MW capacity, although offshore wind for the past ten years in Europe shows the strongest – albeit very fluctuating - growth rate (see figure 2).

The number of firms active in the off- and onshore wind energy business and the degree of concentration also reflect the difference in maturity: one firm, Siemens, accounted for 69 per cent of the offshore wind capacity installed in 2013, whereas seven firms accounted for 57 per cent of the onshore wind capacity (EWEA, 2014; North American Windpower, 2014).

The emergence of offshore wind energy

In 1991, the world's first offshore wind energy farm was erected in Vindeby, three kilometres off the coast of Lolland, Denmark[3]. The wind turbines erected at the site were standard onshore 450 KW turbines from Bonus (now Siemens Wind Power) with a few amendments. Elkraft had asked for bids from four different

[3] The first offshore wind turbine was commissioned in Sweden in 1986, but Vindeby was the first offshore wind park (Petersen & Thorndahl, 2014).

manufacturers of wind turbines, but only two had returned with bids. The remaining two manufacturers were too busy supplying the booming onshore wind energy market to care for this new market opportunity (Petersen &Thorndahl, 2014).

Since the first offshore wind farm was built almost 25 years ago offshore wind energy has progressed by leaps and bounds. In the past decade, offshore wind energy has been the focus of a great deal of attention and the installed offshore capacity has grown dramatically in the last five years. Offshore wind turbines accounted for 15 per cent of wind energy capacity installed in 2013. Although still a small area of wind energy, offshore wind energy has now become a focus area for a growing number of firms of which some are specialising in offshore wind. Meanwhile, there are indications that a wider circle of firms show an interest in offshore wind energy. Even though the offshore wind energy market has grown and is now – with 15 per cent of annual wind power installations– a significant part of total European wind energy installations, it is important to bear in mind that, in commercial terms, there are appreciable differences between offshore and onshore wind energy, with respect to demand configuration, supply structure and technological complexity; differences which clearly affect how the offshore wind energy business system is configured and developing and which also suggests that offshore wind energy is in the process of branching out/bifurcate as an independent industry which continue to have commonalities with the onshore wind industry, but which also as an industry has idiosyncratic traits.

Firstly, offshore wind energy activities are focused on relatively few projects, each of which has substantial volume. This means that decisions regarding the choice of solutions and suppliers are made by a very small number of decision-makers and the market is characterised by project supply and a great deal of uncertainty. In effect, this makes it difficult for firms to balance their presence in the offshore wind energy market with other market activities. *Secondly*, an offshore wind energy farm has a long life cycle: the phases from project planning to de-commissioning may span over a period of 30 years and involve very different actors and business activities throughout their life cycle.

The role of institutions in the development of offshore wind

In order to understand the genesis of the offshore wind energy industry and how its relationship to the general wind energy industry and technology has evolved, it is necessary to go back in start with the events leading up to the establishment of the world's first offshore wind farm in Vindeby in 1991. The Vindeby project was financed by the utility company Elkraft (now part of DONG, the largest offshore wind farm company in the world) mainly as a test and development project. The development status also meant that the project was able to gain minor financial support from the EU.

Along with a growing reliance on wind energy as contributor to the energy mix, discussions concerning the wind possibilities of establishing large wind turbine farms on offshore sites started to emerge already in the late 1970s. In Denmark, the precursor to establishing the Vindeby offshore wind farm was a report developed by the Danish Ministry of Energy in 1983 (quoted in Petersen & Thorndahl, 2014), which concluded that placing wind turbines on offshore sites would provide for better wind quality, higher wind speeds and avoid various problems related to the growing public resistance towards placing wind turbines in populated areas. The conclusions in this report dovetailed with an energy policy strategy and action plan in 1988, suggesting stronger decentralization and a wider use of sustainable and renewable energy sources in the Danish energy system (Petersen & Thorndahl, 2014). At the same time, feasibility studies of offshore wind farms were produced in other European countries.

The construction and particular the operation of the offshore site at Vindeby revealed a number of challenges that called for further technological development. These included issues such as securing blades from strokes of lightning and the ability to continuously adjust for the changing wind conditions at sea. These experiences were used for constructing a second test and develop offshore facility at Tunø Knob in 1995. Here, the ten wind turbines, each with a capacity of 500 KW were delivered by Vestas Wind Systems. Vestas had developed a turbine design allowing for adjustable pitch. The construction and commissioning of the wind farm at Tunø Knob went very well and the farm was able to deliver energy much more effectively and to a considerably lower cost of energy than originally expected. This spurred plans for further expansion and other and much larger offshore wind farm projects in Denmark followed in its wake. In addition, the positive experiences and seemingly steep learning economies inspired energy planners in other countries to consider offshore wind farm investments more seriously.

Today, offshore wind energy technology shows a number of distinctive features. The most proliferated difference between on- and offshore wind energy is the size differential in wind turbines. The average rotor diameter of a contemporary 7 MW offshore wind turbine is 120 meter, corresponding to a swept area of 11,300 m^2, compared to 90 meter and a swept area of 6,400 m^2 for the standard 3 MW onshore turbine. These differences lead to fundamental differences in mechanical strain, which, in its turn, call for different design principles as well as choices of material. Add to this the challenges of erecting and operating turbines in widely different natural environments. As a consequence, a multitude of specialised technologies mushrooms around offshore wind energy, such as special gears, transformers, jack-up vessels and cranes for sea operation.

Retrospectively, this stylized presentation of the industry branching seems to follow a rather established pattern. Accordingly, the rationalities of the individual firm strategies also neatly follow a predictable pattern. However, seen from the perspective of the individual firms in the wind energy industry, the development is not as straightforward as this stylized presentation may let to believe. As further discussed in the following, our data shows that among firms active in the offshore wind energy industry the strategic framing and how it relates to the firms' strategy differs.

4. Data

The analysis is based on a case study of the offshore wind energy industry. Industry evolutions are complex phenomena that call for equal requisite variety in research designs and techniques aiming to capture its emerging properties. For this reason also, and as in all process research designs, the scope of the empirical analysis is unsettled and unfolding (Van de Ven, 2007). These properties of industry evolutions are mirrored in the case study method, which is applicable in situations where there are many variables and where the phenomenon is not clearly distinguishable from its context, thus calling for both multiple sources of evidence and an element of active choice by the researcher in determining boundaries of the phenomenon and combining variables of interest (Yin, 2009; Stake, 2005).

The majority of activity within the offshore wind energy industry is centred in Denmark, and therefore the firm-specific data used in the analysis are collected among Danish-based firms only.

A combination of data is used in the analysis. In addition to various industry statistics, the analysis rests on two data sources: qualitative interviews and questionnaire data.

Over a three year period from 2011 to 2014, a range of interviews have been carried out with managing directors, division managers or technical experts from firms, primarily suppliers of components and services, within the offshore wind energy industry. Interviews were recorded and transcribed. The purpose of the semi-structured interviews was to get an overview of the conditions and challenges facing firms operating within the offshore wind energy industry and, more specifically, to gather information on assumptions and operational logics within the industry.

In the spring of 2014 a questionnaire was mailed to 286 firms presumed to be active within the offshore wind energy industry. Because the offshore wind energy area is still emerging and its boundaries therefore are not well-defined, a range of sources were used for identifying the firms that were likely to be active within the industry. These sources included the Danish Wind Industry Association, the Danish Export Association's Wind Energy Group, and a previous survey of wind energy (Andersen & Drejer, 2012).

The questionnaire focuses on firms' activities within offshore wind energy, but also touches upon activities within the overall wind energy area. Issues covered include firms' activities in relation to the construction and operation & maintenance of offshore wind energy parks; competitive resources and cost drivers; technological overlaps to other markets; and inter-firm (network) relations in terms of trade and knowledge sharing.

122 firms' have answered the questionnaire, resulting in a 42.7 per cent response rate. Eighty-four of the 122 participating firms are identified as being active within offshore wind energy. We assume that firms which are active in offshore wind energy are more likely to have answered the questionnaire than wind energy firms with no offshore activities.

As recommended by Lee (1999), we apply a mixed method approach. The data from the questionnaire have been used in a clustering analysis focussed on identifying different patterns of behaviour among the firms active in the offshore wind energy industry. The interviews have been used for validation and further explorations of the appropriateness of the identified groups of firms.

5. Clustering analysis

A clustering analysis is used to identify groups of firms with similar patterns of behaviour and perception in relation to wind energy in general and offshore wind energy in particular.

Clustering analysis is an important exploratory tool for identifying patterns and structures in data (Govaert, 2009). But clustering analysis should also be treated with some scepticism, not least because the lack of a clear-cut test static for results leads clustering analysis to rely extensively on the judgement of the researchers carrying out the analysis (Ketchen & Shook, 1996). In the present context we include qualitative interviews with firms to qualify the interpretations of the clusters. All interviews were carried out prior to the clustering analysis, and have thus been used in a retrospective manner.

The selection of clustering variables is a crucial step in the application of clustering analysis. The applied approach in this paper for identifying the appropriate clustering variables is mainly inductive (ibid.), although the background information from the interviews pointed in the direction that variables reflecting firms' dedication to wind energy in general were relevant to include alongside variables reflecting firms' dedication to offshore wind energy specifically. Types of activity in relation to offshore wind energy have also been included in the clustering analysis. Accordingly, the clustering variables are the following:

- Percentage of total firm turnover generated from wind energy related activities. Measured on a five-point scale ranging from zero, over "less than 10 %", "10-50 %", "51-99 %" to "100 %".
- Change in turnover generated from wind energy related activities relative to total firm turnover (over the last three years). Measured on a three-point scale ("no considerable change", "considerable increase", "considerable decline").
- Expected change in turnover generated from wind energy related activities relative to total firm turnover (the next three years). Measured on a three-point scale ("increase", "decline" or "no change").
- Plans to increase investments (time and/or money) in acquiring more activities in offshore wind energy. Measured on a two-point scale ("yes" or "no").
- Employees with offshore wind energy as a specific part of their job description. Measured on a two-point scale ("yes" or "no").
- Participation in the construction of offshore wind energy parks (1), operations and maintenance (2) or both (3).

A hierarchical clustering analysis is carried out using Ward's method applying squared Euclidian Distance as the similarity measure. Hierarchical clustering analysis using an agglomerative approach starts out with each object (in the present case each individual firm) forming a group (cluster) and through a series of iterations the closest clusters are merged until just one cluster remains. Ward's method is an approach for minimising within-cluster variance (Govaert, 2009).

Table 2. Agglomeration coefficients

Number of clusters	Agglomeration coefficient	Differences in coefficients	Percentage change in coefficient between levels
10	83.821	6.726	7.4%
9	90.547	8.244	8.3%
8	98.791	11.242	10.2%
7	110.033	11.582	9.5%
6	121.615	15.738	11.5%
5	137.353	20.487	13.0%
4	157.840	36.155	18.6%
3	193.995	50.548	20.7%
2	244.543	84.262	25.6%
1	328.805		

Determining the appropriate number of clusters involves a certain degree of subjectivity. In the present case we have applied the incremental changes in agglomeration coefficients between numbers of clusters for determining the appropriate number of clusters. A large increase in the agglomeration coefficient implies that dissimilar clusters have been merged (Ketchen & Shook, 1996). The question is, however, to determine when an increase is large. In the present case we have set the limit at 20 per cent, which leads the appropriate number of clusters to be three. In addition to looking at the increases in agglomeration coefficients, we have also based the choice with respect to the number of clusters on a certain amount of pragmatism to ensure (i) that the number of clusters is small enough to manage, (ii) that the individual clusters do not become too small and, not least, (iii) that the results are interpretable and meaningful (Mooi & Saarstedt, 2011).

We have, however, also conducted the analysis for four clusters, since there is also a quite large increase in agglomeration coefficients (18.6 per cent) between three and four clusters. The implications for the results of operating with four instead of three clusters are elaborated below.

To test the reliability of the cluster solution a clustering analysis was also carried out using a two-step clustering analysis, which can be carried out without specifying the number of clusters a priori. This method also arrived at three groups of firms. When comparing the results of the Ward cluster analysis with the results of the two-step-clustering analysis, we find that 65.8 per cent of the firms are assigned to the same clusters. Although it is common for results to change when different clustering procedures are used on the same data even when the solution is adequate (Mooi & Sarstedt, 2011), the rather low percentage indicates that the boundaries between the three clusters are not very solid. However, we do not claim that the three clusters represent three stable and unrelated patterns of behaviour; they should rather be perceived as snapshots of firms' different perceptions and behavioural patterns at a specific point in time.

6. Results

As mentioned in the data section, not all firms in the onshore wind energy industry are also active in the offshore wind energy industry. The clustering analysis is only carried out on firms that are active in the offshore wind energy industry.

Table 3. Results of clustering analysis

	Pioneers	Up-and-coming	Occasional	Total	p-value*
Fraction of firms that has generated 51-100 per cent of total turnover the last three years from wind energy related activities	76,5%	35,1%	39,3%	45,2%	0.058
Fraction of firms that has experienced a considerable increase in the relative turnover generated from wind energy related activities over the *last* three years	11.8%	54.1%	25.0%	35.4%	0.003
Fraction of firms that expects an increase in relative turnover generated from wind energy related activities over the *next* three years	0%	97.3%	0%	43.9%	0.000
Fraction of firms that plans to increase investments (time and/or money) in acquiring more activities in offshore wind energy	52.9%	75.7%	39.3%	58.5%	0.001
Fraction of firms that has employees with offshore wind energy as a specific part of their job description	52.9%	67.6%	50.0%	58.5%	0.316
Fraction of firms that participates in the construction of offshore wind parks (1), operations and maintenance (2) or both (3) (1)	0%	37.8%	89.3%	47.6%	
(2)	0%	13.5%	7.1%	8.5%	0.000
(3)	100%	32.4%	0%	35.4%	
Cluster size (n)	17	37	28	82	

* p-values are for the chi-square test of row and column independence (for each variable amongst the three clusters). The tests are for the detailed tables, not the summaries shown here. Detailed tables are available on request.

Table 4. Average centrality measures

	Pioneers	Up-and-coming	Occasional	p-value*
Knowledge network	0.073	0.059	0.041	0.095
Trade network	0.071	0.060	0.050	0.382

Centrality is measured as degree-centrality.
* One-way ANOVA test of difference between groups.

Table 5. Average firm ages

	Average age	Standard deviation	N
Pioneers	12.88	7.991	17
Up-and-coming	22.77	13.782	35
Occasional	29.18	28.270	25
All	22.77	19.684	77

The differences are significant 5 per cent level (ANOVA).

The three identified groups of firms differ in terms of their dedication to wind energy in general, and to offshore wind energy in particular. The individual groups will be analysed further below and their differences will be further explored by including data from interviews.

Pioneers

The group of firms most dedicated to offshore wind energy is also the smallest group. A relatively large proportion of their turnover is generated from wind energy in general.

According to our interviews, which reflect how managers' perceive their firms' competence and knowledge within the offshore wind area, competences may be derived from a narrow and strong focus on one particular area e.g. being a leading firm within the practice of handling and mounting blades on offshore turbine. In other cases, competences are derived from unique combinations of knowledge from other related fields and brining these to fruition within the offshore wind energy area, as suggested in the following quote from a managing director:

> "[Our firm] rarely enters new segments to compete head on with everyone else. We enter because we have some good ideas and solutions that make us stand out from competitors. In this case we already have 20 years' experience in renewables and in being an owner and operator of offshore wind. ..we have seen opportunities by combining these areas of expertise with our competences in oil and gas and in shipping".

The pioneers are committed to the offshore industry because they sense and see this as a unique business area, for which they control unique and adapted capabilities for carrying out a specific value-adding activity adapted to this industry. Perhaps for the same reason, all of the firms in this group are active in both construction and operation & maintenance of offshore wind farms. Because wind is already an important part of these firms' turnover, they do not expect an increase in the relative importance of wind energy turnover. We label this group of firms the offshore wind energy *pioneers.*

It is apparently the most recently established firms that are most dedicated to offshore wind energy: compared with other firms which are active offshore, the pioneers are relatively young firms with an average age of 12.88 years. Firms in this group are also those most centrally positioned in the network of firms that is active in offshore wind energy. The importance of knowledge exchange is an integral part of the development of business solutions. This is also reflected in several of the interviews with pioneers, as exemplified in the following quote from a supplier firm:

> "We are developing some of the heavy lifting equipment [for a specific customer]. ... We have an intense dialogue".

The central position of the pioneer firms, manifested through more ties than the other firms and especially more ties to other key actors, is most distinct in connection with knowledge relations, whereas there are no significant differences in centrality in the network of trade-based relations. Because of their central position, the pioneer firms can potentially play a key role in defining the future growth phase of offshore wind energy industry. As identified by Ter Wal & Boschma (2011), preferential attachment is the driving force behind central actors in a network becoming more central over time, because the probability of being sought out as a partner is proportional to the number of links an actor already has. This process is nurtured by first-mover advantages because the first-mover firms are also often the firms with the 'cutting-edge' technology; and firms with cutting-edge technology are attractive partners to be linked to. In addition, centrally positioned firms have a higher probability of survival, which further increases their centrality (ibid., pp. 925-926).

Up-and-coming firms

The largest group of firms typically generates less than 50 per cent of their turnover from wind energy. However, these are on a development path in which wind energy is set to become an increasingly important part of their total activities. This is illustrated in a quote by a component supplier:

> "Four years ago, we decided to make two separate business units: one for wind energy and one for [x]. I believe we now employ 8 or 9 engineers in the wind division, so for us it is a big department. We have much more wind in our company…We have created a strategy this year with several must-win battles for wind and have achieved two of them already".

Offshore wind energy is apparently important to this development as indicated by the fact that these firms expect to invest more resources in winning contracts in this area in the future. They are ambitious and have made explicit plans for increasing their activities as well as invested resources in the area. We describe this group as *the up-and-coming* offshore wind energy firms.

However, at same time their experience with and dedication to the offshore wind area differs radically from the pioneers. They are in the process of increasing their commitment to offshore wind energy, without necessarily distinguishing strongly between offshore and onshore as separate business areas.

In several cases these firms' offshore activities appear to have originated from being suppliers to the onshore wind energy industry, where they have followed their customers offshore and have started to adapt and versionalize their products according to the changing specifications of their customers. This is reflected in the following quote from an up-and-coming firm:

> "[in offshore wind turbines] there are other temperatures and greater demands on corrosion. You could say that some of the components we use [offshore] are not components that have traditionally been used offshore. This applies to component [x], which we have used in the railway industry, and that's because they were designed [so] that no maintenance was required for ten years. ".

Most of the up-and-coming firms have participated in constructing offshore wind energy farms, either as a sole activity or in combination with operations & maintenance. Where relations are concerned, these firms are slightly less centrally positioned in the knowledge network of firms associated with offshore wind energy than the pioneer firms. However, they are more centrally positioned than the firms in the third and final group (see below).

If a four-cluster solution is chosen instead of a three-cluster solution, this relatively large group of up-and-coming offshore wind energy firms is split into two groups. These two groups mainly differ in their activities, with one group of 16 firms being heavily oriented towards being active in both the construction and operation & maintenance of offshore wind farms; and another group of 21 firms being dominated by firms who are active in the construction of offshore wind farms only. This underlines that the group of up-and-coming offshore wind energy firms expresses a transition phase for firms who are in a process of becoming more dedicated to offshore wind energy. Therefore, over time, we expect the majority of firms in the up-and-coming group to become increasingly more similar to the pioneer firms.

'Occasionals'

We label the third group the *occasional* offshore wind energy firms. In terms of their activities, these firms have several commonalities with the up-and-coming firms. However, they also differ on a number of important aspects in relation to their framing of opportunities and expectations. As pointed out in one of our interviews, there is doubt amongst these firms as to what extent it makes sense to distinguish offshore wind energy as a separate business area. Only occasionally do activities in this industry lead to product adaptation. This viewpoint is reflected in the following quote:

> "If one considers component [x]it will typically be processed a bit differently with respect to the coating. Otherwise the product is identical to the onshore use…we have for many years delivered components without paying attention to whether they were used in offshore or onshore installations. […] Our view is that [offshore] wind is not a mature market and there is no need for us to develop specially designed components."

The occasional offshore wind energy firms generate a relatively small and stable turnover from wind energy. They do not expect to invest more in cultivating offshore wind energy as a business area and they are active either in the construction or operation & maintenance of offshore wind energy farms – but do not combine these two main types of activities. In terms of knowledge sharing networks they are the least central group of firms. This does not necessarily mean that knowledge is not exchanged, but the division of work between the users and the producers, as well as the supplier's commitment, appears to differ remarkably from that of the two other groups of firms. The following quote from an interview with an occasional offshore wind energy firm captures this difference:

> "We collaborate with several of these turbine producers, with respect to the development of components. Typically, we ask for inputs with respect to their demands and then we develop a component we think is in alignment with these requests."

7. Discussion

Studying the emergence of the offshore wind energy industry, the present paper has argued that a new industry does not necessarily come into existence as the outcome of the decline of an existing industry, as proposed by the general industry life cycle model, but can actually appear as branching-out. This means that the new industry co-exists with the existing industry instead of replacing it, and industrial actors may actually be active in both the existing and the branching-out industry. The extent to which industrial actors are active in both business areas depends on their inclination to devote economic and innovative activity to certain types of commercial activities, which in turn depends on their starting points, capabilities, and relative positions vis-á-vis competitors and collaborators.

In order to pursue this argument our point of departure was Ter Wal & Boschma's (2011) industry life cycle model and based on the point of view that industry life cycle analysis is part of a realist tradition, where the researcher is preoccupied with identifying regularities rather than revealing deterministic patterns which lend themselves to prediction. We expected the emergence of the offshore wind industry to reflect an evolutionary process where offshore wind industry emerges as a new business area driven by the interactions of industrial actors. Their acts are based on differentials regarding capabilities and market behaviour, and the process is evolutionary in the sense that the interactions among industrial actors create an increasing degree of variety which is tantamount to the mutation of routines and the creation of novelty. The process would reflect that the industry was progressing through the introductory phase, and that we, consequently, would find an increasing number and variety of firms which would be reflected in a co-existence of different types of collective technological frames.

Based on a triangulation of qualitative and quantitative methods, we presented a case story where technological frames and cognitive schemes for economic behaviour emerge out of the initial utilisation of existing technological frames and cognitive schemes. This process is driven by industrial actors who gradually develop new solutions as existing solutions are being experimented with. Following the branching out of offshore wind energy there is a variety in behavioural patterns which implies offshore solutions differ from the dominant designs in onshore wind. The development takes place as commercial interests and industrial activities in the offshore sector are growing.

The paper identifies three overall patterns of behavioural regularities. *First*, the industry comprises a group of pioneering firms which are strongly dedicated to offshore wind energy. It is a relatively small group which consists of relatively young firms which play a central role in the industry development, both in terms of their capabilities and their core positions at the market. *Second*, a group of up-and-coming firms can be found, which are less dedicated and less centrally positioned in the industry development, but are becoming increasingly engaged in offshore wind energy. They are, on average, almost twice as old as the pioneering firms, but their involvement in offshore wind is less marked than in the case of the pioneering firms. These differences do not mean that pioneers are early entrants while the up-and-coming are late entrants, but the positions they enjoy in the emerging industry are, more or less, equivalent to, respectively, early and later entrants. *Third*, and finally, there is a group of firms which are only occasionally engaged in offshore wind. They are the least dedicated to offshore wind, and although signs of a stronger commitment are present with some actors, their involvement occurs in cases where offshore wind activities spring naturally from onshore wind activities.

We infer that these patterns of behaviour reflect the variety in technological frames and cognitive schemes among industrial actors, but not necessarily within industrial actors. The patterns of differentiated behaviour emanates from clustering analysis, where the location of firms in the behavioural groups depends on the kind of behaviour which they exhibit at the moment of investigation. Thus, the patterns of behaviour reflect previous and ongoing interactions and decisions which have shaped the present position, but they do not necessarily reflect a behavioural scheme which is bound to be replicated in the future. In this sense, we may compare the behavioural patterns with industry recipes (Spender, 1989) or industry mind-sets (Phillips, 1994), which are shared interpretations among industrial actors providing sensible roadmaps, but not specific heuristics for future action. This means that the behavioural patterns, which we have identified, are the outcome of past and present contextual variation, i.e. variation which occur as industrial actors entangle occurring challenges and opportunities, and will be subjected to future contextual variation as the actions of industrial actors shape the development of the emerging industry and create new challenges and opportunities. In conclusion, the behavioural patterns observed are the outcome of dialectical processes where actors shape and are being shaped by the conditions in which they act, and where the conditions are continuously changed as the cognitive schemes and ensuing decisions of industrial actors change.

Within our interpretive scheme, i.e. the Ter Wal & Boschma (2011) model, the offshore wind industry is still in the introductory phase in the sense that the number of firms is low, the variety among firms is high, and the technological regime is characterised by high degrees of tacitness and uncertainty. It is difficult to argue that the industry is heading towards the growth phase, although the occurrence of groups of firms may indicate that clusters are appearing, and that networks with core and periphery structures are emerging. As argued above, the grouping of firms is more likely a sign of ongoing variation, and as shown previously the networks are not yet significantly established structures. The non-solid boundaries between the identified groups of firms might be expected in a process of branching out, where mutation of routines and elaboration of cognitive schemes are continuously creating new divisions of labour and shifting positions within the overall system of industrial activities.

This observation might be a contribution to improving the interpretive scheme which we have used in this paper. A basic premise of the industry life cycle approach is that it is possible to define qualitative shifts in the evolution of an industry, i.e. the points of no return where an industry progresses from one stage to another. While this problem of definition is difficult to solve in cases where new industries emerge as old industries decline, it becomes even more difficult in cases where new industries occur gradually as a branching out from existing industries which do not decline, but persist. The basic question is: When is the industry branched-out? The solid formation of groups of firms, indicating that regularities are becoming strong, might be an indicator of the point of no return where a new industry shifts from being embedded in an old industry to becoming an industry in its own right.

Our analysis has pointed to the fact that some of the concepts that are crucial for understanding the evolution of firms and industries are not well-defined. In particular, the definition of what is an industry is of paramount importance for the study of the evolution including the emergence and decline of an industry. Previous studies of industry life cycles have been carried out ex-post and the industries have therefore been defined in retrospect, without too much effort on specifying the boundaries to related industries. For instance, Abernathy & Utterback (1978) used the same terminology to study industrial innovation in complex multi-technology areas such as automobiles and aircrafts as well as in the much more narrow area of light bulbs. In the present analysis, where we aim to understand the development of industries while the process is ongoing, the task of identifying the boundaries of an industry becomes much more difficult – for researchers as well as firms active within a business area. We have defined an industry as a business area based on a combination of technological solutions and market opportunities which are specific for that area. However, if we want to increase our understanding of processes of industrial evolution it is important to dedicate more effort into specifying what an industry is.

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