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Systemic Innovation in a Distributed Network: Paradox or Pinnacle?

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Abstract:
Previous research has suggested that there is a dichotomy of organisational practices: companies involved in autonomous or modularised innovations, it is argued, benefit from decentralised approaches where coordination primarily takes place through the marketplace, whereas the benefits of systemic innovation are said to be appropriated best by centralised organisations. However, case studies of subcontractors to the Danish wind turbine industry suggest that the ability to meet heterogeneous demands plays an important role for the success of different forms of organisational practices in relation to innovation. The modularised versus systemic architecture approach therefore appears to be a too sweeping dichotomy for describing what can better be perceived as an array of different practices for balancing innovation contribution with the ability of individual firms to appropriate innovation benefits – and a heterogeneous market perception is a core element in building and sustaining this ability.

Key words: Organisational Forms, Innovation System, Knowledge Complementarities, Value Appropriation
JEL Codes: L14, O31, O34

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1. Introduction

Over the last few decades, it has become widely accepted that innovation is an interactive process involving the innovative firm *and* its environment (Kline and Rosenberg, 1986; Lundvall, 1992; Carlsson et al., 2002) - with the qualification that the ability to appropriate economic returns from different types of innovation benefits from different ways of organising the innovation process. What is important here is the interdependence of innovation activities across organisational boundaries and how this affects the ability of firms to appropriate returns from their investments in the creation of knowledge goods. Often, this may be solved by creating an artificial form of scarcity, using devices such as patents and other forms of IP rights that can be protected by law. However, as pointed out by Richardson (1972), development activities often lead to equal exchanges of assistance, where it is hard to specify ex ante who is the greatest contributor and where risks from shirking are obvious (Alchain & Demsetz, 1972). Research on the appropriation of individual returns from knowledge investments generally distinguishes between innovation activities that are clearly separable/modular or strongly interdependent/systemic in nature (Chesbrough & Kusunoki, 2001). Companies involved in autonomous modularised innovations are thus argued to benefit from decentralised approaches in virtual companies which largely coordinate through the marketplace. Conversely, in the case of systemic innovations, where the reaping of economic benefits depends on related complementary innovations, the appropriation of innovation benefits is said to take place best within a centralised organisation, i.e. in integrated companies that have control of the activities which need to be coordinated by means of a hierarchy (Chesbrough & Teece, 2002). This dichotomy indicates that autonomous actors following a distributed innovation practice will face difficulties in appropriating benefits in an industrial setting characterized by an interdependent component architecture and a correspondingly systemic and integrated product architecture.

However, research on innovation activities related to the development of wind farms suggests that the most successful form of organisation of innovation depends not only on the type of innovation, i.e. systemic or modular, but also on the nature of the industry and the strategy or approach pursued by innovative firms. Dynamic industries – such as the wind turbine industry, where Denmark is a world leader - which are characterised by continuous, albeit stepwise, technological development, may thus achieve successful systemic innovations through distributed innovation processes.

The paper is structured as follows: Section 2 briefly presents the success story of the Danish wind turbine industry. Section 3 reviews the literature on the organisation and appropriation of innovation benefits in distributed and integrated innovation regimes respectively. In section 4, five cases of subcontractors to the Danish wind turbine manufacturers are presented. These in-depth case studies are the empirical core of the paper. Section 5 discusses the innovation practices of the Danish wind turbine industry, based on an analysis of the innovation practices reflected in these case studies, and proposes a framework for the emergence of distributed innovation systems in a systemic setting. Finally, section 6 presents the implications for research and practice.

2. The success story of the Danish wind turbine industry

Wind has been used as a source of energy in Denmark since at least the mid fifteenth century. Windmills were primarily used for grinding corn or in saw mills until the late nineteenth century, when the Danish physicist and meteorologist Poul la Cour began experimenting with wind turbines as a source of electricity. When la Cour died in 1908, approximately 60 wind-based power plants had been installed in Denmark, most of them only providing electricity for a single farm or estate, and wind energy came to play an important part in bringing electricity to rural Denmark. The increasing use of fossil fuels throughout the twentieth century led to a reduction in the number of wind turbines, although this was halted somewhat during the two World Wars when restricted access to fossil fuels led to a temporary advance in wind technology (Petersen, 1993).

The modern Danish wind turbine industry has its roots in the oil crisis of the 1970s. In 1972, a Danish carpenter, Christian Riisager, built a wind turbine in his back yard, which was the forerunner of the production of 72 wind turbines over a 2-year period in the mid-1970s (Petersen, 1993; Jensen, 2003). Heavily inspired by Riisager, the so-called ‘teacher group’ at Tvind, a controversial Danish school community, set out to create the world’s largest windmill, ‘Tvindkraft’. In turn, this group of amateurs came to provide the inspiration for several other pioneers of the Danish wind turbine industry (Jensen, 2003). The main drivers of the early development of the industry either diversified into wind turbine production in response to stagnating markets in, for example, agricultural equipment, or were small do-it-yourself entrepreneurs. This was also the case for core subcontractors. For example, Vestas Wind Systems, which – following its acquisition of NEG Micon, and Siemens’ acquisition of Bonus Energy - is the largest and only remaining Danish-owned wind turbine producer, emerged out of a forging shop; and LM Glasfiber - now a major blade producer - was originally a producer of fish crates and sail boats in the late 1970s. These were very hands-on firms, which, in the early years, carried out no formal R&D activities. Learning took place through practical experimentation, although more formal design and development functions gradually emerged (Karnøe, 1999; Jensen, 2003).

As a result of the hands-on approach, innovation in the Danish wind turbine industry was stepwise and distributed between actors from an early stage, unlike US wind turbine manufacturers, who concentrated more on making major technological breakthroughs. The design and production of several components was carried out in a collaborative network, which, with its many SMEs and dedicated research institutions, meant that Danish wind turbine producers were able to benefit from the competencies of firms distributed across a range of suppliers in a connected network.

The Danish wind turbine industry grew rapidly during its first decade, and accounted for more than 80 percent of the world market in the late 1980s (Karnøe and Jørgensen, 1995). While the world market in the 1980s primarily consisted of Denmark and California, new markets have emerged during the last two decades, making wind power currently the fastest growing energy resource in the world.[1] In 2003, Danish producers accounted for approximately 38 percent of the world market, with exports making up more than 90 percent of total sales. Wind energy generates approximately 20 percent of the electricity consumed in Denmark, which is equivalent to the share of electricity generated by nuclear power in the US.[2] Europe, where wind accounts for approximately 3 percent of the total production of electricity,[3] is currently the largest world market for wind power, followed by the US, but markets in India and China are growing rapidly. Total world capacity was 47,000 MW in 2004,[4] approximately half of which can be attributed to Danish- produced turbines.[5]

The dominating size and innovative input of the Danish wind turbine industry has been widely acknowledged and it is generally agreed that the bottom-up approach of the Danish industry is superior to the top-down approach of the wind turbine industry in the US (see, for example, Garud and Karnøe, 2003). However, the innovativeness of the Danish wind turbine industry is not

[1] The European Wind Energy Association; www.ewea.org, Wind Energy Facts.
[2] The Danish Wind Industry Association: www.windpower.org and US Energy Information Administration: www.eia.doe.gov.
[3] American Wind Energy Association: Global Wind Energy Market Report 2004
[4] Global Wind Energy Council: www.gwec.org.
[5] The Danish Wind Industry Association: www.windpower.org.

reflected in international patent statistics. While approximately 200 inventions related to the industry were published each year on a world basis in 1985-95, Danish firms only accounted for 1.5 percent of all patent applications, and Japanese, Eastern European and American wind turbine producers filed considerably more applications. During the period 1994-96, Bonus Energy[6] was the 11th most active patent applicant in the global wind industry, with 3 patent applications. Japan's Mitsubishi Jukogyo Kabushiki Kaisha topped the world list with 21 patent applications during the same period (Danish Patent and Trademark Office, 1997). Analyses of data from the European Patent Office covering the period 1996-2005 show a drastic increase in patenting activity by Danish wind turbine manufacturers since the late 1990s, including sporadic patenting from different subcontractors and increasing patenting activity by the largest Danish wind turbine producer, Vestas Wind Systems, as well as the blade producer LM Glasfiber. The level of patenting activity in the total network remains relatively low, however. Thus, there appears to be a different appropriability regime in the Danish wind turbine industry compared with the US and Japan. Appropriability regimes are usually perceived as being aligned with industry rather than national borders. For example, Levin et al. (1987) find considerable interindustry variety in the level of appropriability and the mechanisms that provide it. However, they also find that other means of appropriation, such as secrecy, learning advantages, and sales and service efforts generally play a more important role than patents as a means of appropriation, although some industries rely heavily on patenting. The differences in patenting activity among actors in the wind turbine industry in Denmark and the US and Japan indicate that appropriability regimes not only differ between industries, but also between firms operating in the same industry in different countries. As shown in the following, the limited use of patenting in the Danish wind turbine industry may be a reflection of how the processes of technological development are organised in the industry.

3. Theoretical considerations on the distributedness of innovation and the appropriability of economic benefits

In recent years the role of firms' capabilities and resources for understanding innovative capabilities and processes has been downplayed in favour of a more network-oriented view of innovation. A growing number of research contributions point to the importance of critical factors external to the firm for explaining processes and outcomes. Studies in a wide range of industries, including biotech

[6] Bonus Energy A/S, which was the second largest Danish producer of wind turbines, was acquired by German Siemens in 2004 and continues its wind turbine production in Denmark under the name Siemens Wind Power A/S.

(Powell et al., 1996), open source software (Bitzer & Schröder, 2005), and petroleum (Acha and Cusmano, 2005), point to the importance of network factors for understanding the innovation process and its drivers.

The focus on the distributedness of processes of technological innovation across firm boundaries has led to the emergence of the notion of 'distributed innovation', which explicitly refers to situations where technologies and other capabilities required for innovation are distributed across a range of firms and other knowledge-generating institutions (Coombs and Metcalfe, 2002). A related concept, although aimed more specifically at the market for innovations rather than the innovation process itself, is 'network externalities', which refers to situations where the benefits to users increase with the number of other users acquiring compatible items (Katz and Shapiro, 1986). Common to the literature on distributed innovation and network externalities is that the standardisation of interfaces is identified as a key factor for accruing the benefits of innovation. This is associated with the view presented by Chesbrough and Teece (2002; see also Teece, 1996) that different types of innovation profit – in terms of appropriating the economic benefits - from different ways of organising the innovation process. The literature on appropriability and organisation distinguishes between two main types of innovation: modularised/autonomous integration and systemic/integrated innovation.

The distinction between different types of innovation according to their systemic nature dates back to Henderson and Clark (1990), who distinguish between innovations that change only the core design concepts of a technology, but leave the interfaces between concepts and components unchanged, and innovations that change the interfaces between components. With regard to the former, de facto and de jure standards articulate and codify interactions among components. Modularity may be influenced by companies which apply specific standards that are later adopted by other key players in the industry. However, as such interfaces become the accepted standard in the industry, they also become an inherent part of the industry characteristics, setting the boundaries for the scope of these modularity decisions. For instance, in the case of bicycle manufacturers, interfaces between components are clear-cut and global standards prevail. Thus, a company like Shimano can develop new types of gears irrespective of wheel manufacturers or other complementary components manufacturers. One component can be changed without having to adjust the rest of the system which the component is part of – hence the label modular or autonomous innovation. With an innovation of the second type, a change in one component also implies changes in the linkages between components, due to the complex nature of interrelations among the components constituting the whole. For instance, the construction and development of fighter jets represents a technology which is clearly systemic, since changes in the functionality of almost any component - from weaponry systems to the landing gear – are intricately related to a range of other components in the jet. The label systemic (or integrated) thus refers to innovation which requires subsequent alterations in the system of which it is a part (Teece, 1996; Chesbrough and Teece, 2002).

The organisational governance structure best suited for appropriating returns to those who possess knowledge goods differs according to whether the technology used is modular or systemic. Chesbrough and Teece (2002) argue that, in cases of modularised innovations, firms benefit from decentralised approaches in virtual companies, because the information needed to integrate an autonomous innovation with existing technologies will in most cases be well understood and possibly codified in industry standards, and such codified information is difficult to protect. Therefore, it can be a costly strategy to try to internalise all the necessary types of knowledge and information, which are relatively easy to acquire from sources outside the firm, in one single firm. The motivation to join a knowledge-sharing network is thus the access the network provides to information and knowledge, as well as to channels of communication about technological opportunities and obstacles (Powell et al., 1996).[7] Standards connecting different layers of technology encourage competition among suppliers of specific technologies. Likewise, Chesbrough & Teece (1996) argue that, in cases of systemic technologies, value is best realized in the centralized organisation, and achieving control of innovation activities is necessary in order to control coordination and facilitate rapid mutual adjustment. Vertical integration of activities could also be seen as a way to avoid the capability-related vulnerability which a firm engaged in distributed innovation processes is subject to, especially in periods with rapid technological change, because such a firm is not only dependent on its own capabilities being updated and relevant, but also on the development of the capabilities of its collaboration partners (Afuah, 2000). Teece (1996)

[7] However, according to Powell et al. (1996), learning networks are important when the knowledge base is complex and expanding, and much of the relevant know-how is neither located inside an organization nor readily available for purchase - that is, when the sources of knowledge are disparate and the pathways of technological development uncharted - and not when knowledge is codified as easy accessible, as proposed by Chesbrough and Teece (2002).

therefore proposes multi-product integrated firms as the most appropriate types of organisation for successful development and commercialisation of systemic innovations.

Chesbrough and Kusunoki (2001) argue that the character of a technology is not static, but rather evolves from being systemic in the early phases, to being modular, and often back to being systemic again. Similarly, Christensen & Raynor (2003) point out that an important competitive driver in industries is pushing the technological frontier through innovative designs while at the same time addressing customers' requirement costs efficiently, through the development of modular designs. According to Chesbrough and Kusunoki, the optimal organisational configuration of a firm must evolve with the technology if it is to continue to capture value from its innovative activities. This is outlined in figure 1 (adapted from Chesbrough & Kusunoki, 2001):

		Technology type	
		Modular	Systemic[8]
Organisational governance	Decentralized	Proper alignment Value realized only within technology layer	Misalignment Cannot manage interactions Insufficient infrastructure
	Centralized	Misalignment Unnecessary internal coordination Reduced economies of scale	Proper alignment Value realized in the system Effective coordination of undefined interactions

Figure 1: The alignment of technology and organisation according to Chesbrough and Kusunoki (2001)

Misalignment occurs when organizational governance is overly complicated and costly compared with the coordination challenges involved. As pointed out by Richardson (2003), the cost of administrative coordination escalates disproportionately with its scope. In cases where market

[8] Chesbrough and Kusunoki most often use the term 'integral' rather than 'systemic' to denote complex technologies where a change in one component also implies changes in the linkages between components.

mechanisms are efficient and modular activities are co-ordinated by hierarchy, there is a misalignment, since the organisation is less efficient than the market. On the other hand, according to Chesbrough & Kusunoki (2001), misalignment may also occur when the intricacies of systemic technologies rule out an intellectual property rights regime which enables individual firms to appropriate their knowledge benefits. Intermediate markets do not function efficiently in systemic technologies, because interdependencies among technological layers are poorly understood by individual firms. Consequently, in cases of systemic technology, intermediate markets are ridden with market failure. In these cases, innovative firms will withhold their information, since they would expect the value of their knowledge assets to erode due to the opportunistic behaviour of their counterparts.

The major problem of the decentralised or distributed organisation of systemic innovations is the lack of coordination mechanisms in the market. However, as the case of the Danish wind turbine industry presented below will illustrate, systemic innovations can also occur successfully in distributed innovation networks. Both Chesbrough and Teece (1996), and Chesbrough and Kusunoki (2001), regard this as paradoxical. In the following, therefore, we will discuss how this apparent paradox can be explained, and how these ‘modularised’ actors appropriate benefits from innovative activities associated with systemic technological architectures. Part of the answer might be found in research areas not commonly associated with the literature on the organisation of innovation activities, e.g. in the industrial district literature, with its emphasis on coordination as a result of more or less formalised cooperation among the various parties (see, for example, Dei Ottati, 1994). The presence of local customs, as well as the importance of reputation for further collaboration, may partly explain why collaboration appears to have been preferred over integration as a coordination mechanism among subcontractors in the Danish wind turbine industry.

4. System properties of the Danish wind turbine industry

As a product design, a wind turbine is complex and systemic in nature. In order to withstand the extreme conditions they are often exposed to, wind turbines must be carefully designed and their subsystems strongly interrelated. Producers are constantly trying to improve existing designs in order to increase the energy efficiency of the turbines, which in turn requires the continuous improvement of materials, components and product designs – a process in which suppliers play an important role. Because the industry is characterised by a high degree of interdependence between elements, there is little room for modularity in most parts of the system. This means that industry-wide component standards defining the interface between the various components are lacking. Below, the systemic features of the Danish wind turbine industry will be studied in more detail through five case studies, with a particular emphasis on the systemic nature of innovation activities and how individual firms reap benefits from participating in these activities.

Data and methodology

The empirical part of the paper is primarily based on case studies of subcontractors in the wind turbine industry and on the assumption that cases have an empirically objective stance with clearly identifiable boundaries (Ragin, 2000). Given that the purpose of this study is chiefly to explore and detect possible patterns of inter-firm organization of innovation activities and corresponding benefits from participating in innovation activities, a case study approach taking firms as the analytical unit is a relevant research strategy (Yin, 1994). A case study approach is recommended when the issues are of a complex and evolving nature and where alternating between the empirical field and different theoretical frameworks can be useful for generating insights (Yin, 2003; Orton, 1997). Thus, the aim here is not primarily to test deduced propositions in the traditional positivistic sense, but to interpret and develop possible theoretically informed rationales, basing the efforts in empirically identified phenomena (Glaser & Strauss, 1967).

Selection of cases and data collection

Compared with single-case studies, a restricted number of multiple case studies optimizes the possibility of getting close to cases and detecting subtle differences while at the same time studying phenomena in different empirical contexts and contrasting their findings (Eisenhardt, 1989). As pointed out by Glaser & Strauss (1967), it is important to strive for empirical plurality in the selection of cases in order both to increase variation and test and develop emerging findings. Initially, a range of potential case companies was selected, using the Association of Wind Turbine Manufacturers supplemented with the Internet, news clipping searches and expert interviews. This search yielded a list of approximately 100 subcontractors located in Denmark. The five companies selected for the study represent a broad range of the components and processes involved in the development of wind energy, including the mechanical and electrical systems involved in both the components and the wind farms, as well as the building components of the turbines. The companies also reflect the variety within the industry in terms of structural characteristics, such as number of employees and turnover (see table 1).

Data were collected from interviews with persons responsible for the firms' innovation activities, typically technical or division managers. Most interviews were conducted with both authors as interviewers and two interview persons, yielding interviews with 9 persons in the case firms and 3 interviews with experts from industry organizations. These interviews were conducted in person in order to maximize closeness to the data, which is important for subsequent interpretation, since researchers' feelings and interpretations are the primary tools of qualitative research (Merriam, 1998; Gilbert, 2002). In addition to these interviews, background information was obtained through informal talks with managers from the industry at business or research seminars. The interviews were conducted using a semi-structured interview guide, which acted as a guideline for the conversations with the interview persons. Interviewees were allowed to freely expand on their answers or challenge the questions, which prompted further questions from the interviewers, thus resembling more of a dialogue than a questionnaire-based interview. The interviewers prepared for each interview using data in the form of newspaper clippings, company-related material available on the Internet, and various forms of archival data in order to improve their pre-understanding and prepare for specific questions. The typical duration of interviews was 90-120 minutes. A tape recorder was used for all interviews, which have been transcribed, yielding more than 175 pages of text. In addition, various kinds of company materials were offered on site. Following Miles and Huberman (1994), given the nebulous nature of the object of their scientific interests, social science researchers should be aware of their own theoretical predispositions and ensure a high degree of validity and reliability through an explicit process of data analysis. In the process of developing categories and inferences, both a priori and a posteriori coding strategies were used, allowing for interaction between data- and theory-driven insights (Sinkovics, Penz & Ghauri, 2005). Qualitative analysis software may be useful for this purpose, since it reduces the possibilities of human error and increases the possibilities for emerging insights. Therefore, data coding has been highly structured, using Nvivo, a recognized software package for structuring qualitative data analysis.

Profiles of the interviewed companies

Table 1 presents an overview of key data on the interviewed firms.

Table 1: Key figures for the case firms

	LM Glasfiber	Densit	AVN Hydraulics	CC Jensen Filter division	VBE
Total number of employees	2,400	66	50	150	2
Year of founding	1940 (As Lunderskov Møbelfabrik)	1983	1933 (AVN Group) 1978 (AVN Hydraulics)	1953	App. 1955 (Villy Bruun) 2002 (VBE)
App. year of entry into the wind turbine industry	1978	2000	1978	2000	1990 (Villy Bruun) 2002 (VBE)
Turnover (DKKm) (percentage related to wind energy in brackets)	2,260 (100%)	115 (10%)	N.A. (70%)	137 (66%)	4 (50%)
Components	Wind turbine rotor blades	Grout – technical cement for offshore foundation	Hydraulic components for blades and towers	Oil filter systems for gears and moving parts	Construction services and consultancy
Development activities related to wind turbines	Partnering with customers on blade manufacturing	Developing systems and material for anchoring offshore wind turbines	Developing hydraulic systems that affect the construction of the turbine nacelle	Developing oil filter systems calibrated to specific turbine dimensions and working conditions (e.g. offshore)	Development of power components for reducing construction and maintenance costs; development of connections to the high-voltage grid
Other areas of activity (non-wind related)	None (previously involved in the production of sail boats and chassis frames for trains)	Industrial flooring, wear protection, security barriers, strengthening of offshore structures (oil and gas platforms)	Industrial hydraulics in various forms for special-purpose machinery (e.g. building and construction), ships.	Metal foundry work (noble metals) for the shipbuilding industry, windows for ships, power stations, vessels.	Sister companies within the business group are involved in electrical wiring for industry and households and in process technology (software)
Patent applications	Yes	Yes (but not specifically related to wind)	Yes	Yes	No

LM Glasfiber started as a producer of wooden furniture in the 1940s, but began exploring the commercial application and uses of fibreglass technologies in the production of sailboats and caravans in the early 1950s. The company produced its first rotor blade for wind turbines in 1978.

Today, LM Glasfiber is a leading producer of rotor blades, with production facilities and customers in Denmark, Southern Europe, the US and Asia.

Densit is a spin-off from Aalborg Portland, a leading producer of cement, owned by the FLS Group and located in Aalborg, Denmark. The division was established in the 1970s, based on the development of densit, which is the brand name of its product. It offers solutions for industrial strengthening and repair based on high-strength and dense cement-based materials. Main customers are found in areas such as industrial flooring, offshore foundations and similar areas. The focus of the company in the wind energy industry is on the offshore sector, with a sales division dedicated to this business area.

AVN Hydraulics is a division of the AVN Group, which is a medium-sized Danish subcontractor involved in a range of different industries, such as tool production, sheet-metal processing machinery and various other areas. The hydraulics group is a strategic supplier of hydraulic solutions and maintenance in a variety of industries, but with a specific focus on wind turbine blades and towers.

CC Jensen filter division is the largest division in the CC Jensen Group. The CC Jensen Group is a small-to medium-sized enterprise, which manufactures off-line oil filtration systems, ship windows and metal castings. The filter division is particularly (but not exclusively) focused on the wind turbine sector, which provides most of its turnover.

VBE is part of VB Holding, and implements high- and low voltage works for energy-related projects such as wind turbines, both on- and offshore. The company takes on turnkey projects related to connecting off- and onshore wind turbine parks to the electrical power grid. It has a strong focus on the wind turbine industry, but is also active in other industries, such as the power plant industry.

Findings from the case studies

In order to best structure the findings from the case studies, these are discussed under the following three headings: First, the nature of technology and of innovation activities, following the categorization of technologies into modular and systemic archetypes. Second, the organisation of collaboration on technology development across organisational borders. Finally, processes of individual appropriation of knowledge returns in these companies.

The nature of technology and of innovation activities

First, it must be determined whether the nature of the technology used in wind turbine plants is best described as modular or systemic. As has often been pointed out, the theoretical clarity of the product architecture concept does not always match empirical realities (e.g. Christensen, 2003). All suppliers to the wind turbine industry agree that even among the most vertically oriented suppliers, critical knowledge components are left to complementary suppliers. Moreover, due to the interdependence of the technology used, suppliers are often involved in system-integrated debugging activities, as new designs are tested or the sources of specific technological problems are detected. One example of this interdependence is the use of mock-ups at sea, where suppliers jointly develop a shared procedure for establishing the most efficient wiring of electricity from the power generation components to land. Another example is the joint efforts of suppliers, and even competitors, in debugging activities (such as seminars, workshops and erecting mock-ups) to solve specific problems related to the gearing of wind turbines, which in 1998 caused a major break-down on a NEG Micon wind turbine farm. This is a necessity given the complexity of the wind turbine plants, which combine a range of very different technologies, since maintaining and updating all critical knowledge areas would be prohibitively costly for even the largest manufacturers in the industry.

In all five case studies, interview persons were asked about the nature of coordination among subcontractors in the industry, using the Thompsonian framework for assessing technological interdependencies as the core reference. Thompson (1967) describes the interdependences of tasks carried out in a specific technological setting as either pooled, sequential or reciprocally interdependent, referring to the complexity of the underlying coordination of activities. Pooled interdependence is a situation similar to the one described in modularization literature, whereas reciprocal, and, to some extent, also sequentially related technologies are associated with interdependent technologies and requires more complex forms of coordination.

Studying the nature of technology in the wind turbine industry revealed an apparent paradox with respect to the modular-systemic technology dichotomy discussed earlier. Although not recognising de facto or de jure standards, almost all the interviewed firms saw themselves as developing their skills and competencies independent of other suppliers. All cases displayed a complex pattern of interaction, displaying a strong degree of independence with regard to their technological focus, while at the same time revealing a high degree of holistic thinking and interdependence when designing and developing specific components of the wind turbine or the facilitating structure of the wind farm.

As expressed by a manager of Densit, one of the case companies:

> *What we provide here is a fairly standardized product. However, we do provide consultancy services with regard to technical solutions, to those who are interested...to an increasing extent we are contacted by the large engineering companies, responsible for design of offshore parks, and we provide them with data and we help them by setting up tests that may optimize their use of our material.*
>
> [Anders Møller, Chief Sales Executive, Densit]

In the case of Densit, this balance between in- and interdependence also relates to the development of entire systems. Likewise, AVN has developed a new hydraulic system to specific turbine dimensions and working conditions. This system had been developed for a specific customer order for NEG Micon, but when this company merged with Vestas Wind Systems the order was cancelled. However, since AVN had invested significant resources in developing the new system, it decided to continue development regardless. At the moment AVN is negotiating the sale of the system with several international manufacturers of wind turbines.

Thus, even though components are developed independently, they are also seen as highly interdependent and there is a shared focus on increasing the efficiency of the system as a whole (i.e. developing the perfect machine), which may imply compromises with respect to the efficiency of the individual component. This viewpoint is supported by the interview with LM Glasfiber:

…they [the producers of wind turbines] contribute with knowledge at one level. One can say that those who are very talented in constructing the turbines, and who understand the interrelations, are able to reduce the loads and make something more optimal. And that allows us to make a rotor blade which is more optimal for them.

[Anders Christensen, General Manager, LM Glasfiber]

Likewise, CC Jensen explains how they coordinate their activities with the development activities of their customers and with other suppliers. As well as having a close relationship with customers, involving a high degree of mutual adjustment and coordination, they also see themselves as providers of a fairly generic technology which can be used in a range of contexts. But they have also used their competencies to develop an oil filter specifically designed to meet the extreme weather and temperature conditions of offshore wind turbine plants.

This is our design, but it has been tested and further developed together with the wind turbine industry. There are specific conditions for offshore which you do not find onshore. One is the occurrence of volatile temperature shifts, another is the high degree of salt in the air, which may call for specific measures when developing our machinery.

[Ulrich Ritsing, General Manager, CC Jensen]

So far, the duality of a systemic orientation while at the same time focusing on the development of individual components has not changed as the industry has evolved, contrary to the general predictions of technology evolution proposed by Chesbrough and Kusunoki (2001). For instance, as wind turbines grow in size, the interdependence of its parts becomes increasingly pronounced, the loads on the turbine as a system increasing progressively rather than proportionally. As the General Manager of CC Jensen says:

On the new three megawatt turbines, which are currently being tested, we are a more integrated part of the overall design than we ever were before.

[Ulrich Ritsing, General Manager, CC Jensen]

This was echoed by the General Manager of LM Glasfiber, commenting on the growing size of wind turbines:

> *…when you have a tower of 90 or 120 metres, it matters how much load you place at the top. It's related to the price of the tower, it's related to the foundation. And therefore one can say that it is the same parameters, but they are assigned different priorities when the height of the tower increases.*
>
> [Anders Christensen, General Manager, LM Glasfiber]

However, the greater interdependence has not led the rotor blade producer to consider integrating more functions and components within the organisation. Conceivably, for example, it might be advantageous for the blade producer to also control the production of the hub that the rotor blades are connected to, but this is perceived as a totally different product, based on other types of knowledge and technology. Thus, despite a growing interdependence and correspondingly more complex coordination regime, reflecting what Thompson described as reciprocal interdependence across activities and sub-processes, the distribution of innovation activities across actors prevails.

Organisation of innovation activities

The previous section described the distributedness of innovation activities. In this section, the patterns of organizing distributed innovation in the case firms are discussed in more detail. Turbines for offshore locations are attracting considerable development efforts, since the sea provides opportunities for larger turbines. Although many new offshore plants are planned, and some already under construction, all the interviewed firms agree that there are still formidable innovation challenges, and that the development of each new offshore wind turbine plant must be seen as a large-scale experiment in its own right, where construction and development activities interlap. This may be one reason for the open door policy in most of the companies that have been interviewed. There is a shared perception that companies need to let their R&D personnel exchange knowledge in order to improve on the technology. Parallel to the observations of Brown & Duguid (1998), the exchange of interfirm knowledge seems to be facilitated by the existence of knowledge ecologies - communities which span organisational borders, where knowledge is continuously embedded in practice – some of the respondents even claiming that the exchange of knowledge is more intensive and elaborated in interfirm rather than intrafirm settings (Grant & Spender, 1996). A good example from the data is Siemens, a multidivisional company containing several divisions that are world-leading power and electricity companies in their own right. Notwithstanding, Siemens Wind Power obtains knowledge on the connection of wind turbines to the power grid from VBE, due to the strong knowledge community there. At the same time, these relations are informal in nature. Contrary to others' findings (Teece, 2001), the intellectual property right protection of external transfer of technology through licensing, formalized technology transfer agreements and similar strategies are not used to a very large extent in the industry. However, there is increasing knowledge competition and secrecy involved in planning interfirm organisation in such a way as to protect company knowledge, particularly as regards withholding information from customers. CC Jensen, LM Glasfiber and AVN all pointed out that they are becoming increasingly aware of the importance of enforcing Intellectual Property rights. Densit and VBE, on the other hand, saw the sharing of information as a sine qua non of their operations, so there is no consensus on this. At the same time, most of the companies interviewed had positive experiences of establishing and organizing various forms of interfirm quasi organizations for various technology development purposes, and they had no intention of withdrawing from these activities. For this reason, the organisation of innovation activities is fluid and strongly team-oriented, where the teams respect organisational borders to a limited extent only. This is illustrated by Lars Rasmussen, VBE:

> *When Bonus (a wind turbine manufacturer which is now owned by Siemens) established the Rødsand offshore park, they came to us and said: before we install 72 turbines at sea, it would be a great idea if you would collaborate with us on establishing a mock-up turbine for testing purposes…together with a number of other suppliers we worked on testing various concepts. We rented a cottage five minutes from Nyborg Harbour, which were our quarters. At Nyborg Harbour we worked on all 72 turbines - together with people from the wind turbine manufacturer and other subcontractors - all summer.*
>
> [Lars Rasmussen, General Manager, VBE]

Another example is AVN, who used the test facilities of a former customer to try out their new hydraulic design, but then decided to build their own test facilities when the customer merged with Vestas Wind Systems. In other cases, engineers from the subcontractor firms became temporary employees in the partner firms in order to ensure the transfer of “sticky” knowledge. This is the case in both CC Jensen and LM Glasfiber. In the former, the key person responsible is in contact with their largest customers on a weekly basis and acts as a knowledge broker between them and the company. As a result, CC Jensen participates in several groups in solving specific technology-related matters. LM Glasfiber has developed a project-based organisation centred on the delivery of new blade designs. They explain how technology-related knowledge is transferred in the following way:

> *The procedure is that in the final four to six weeks of a blade development project one of our production engineers, who has been involved in the project, follows the product to the customer and stays with the customer's organisation for that period of time. I think this is one of the more innovative initiatives we have taken in this firm.*
>
> [Anders Christensen, General Manager, LM Glasfiber]

Similarly, cross-firm meetings and seminars are frequently initiated by individual firms or other actors, such as universities or even the industry association, which involves a broad range of suppliers as well as competitors. Some of these meetings concern problems faced by a broad range of actors in the industry. One such case concerned the breakdown of gear systems a few years ago. Here, competitors collaborated with potential complementary suppliers, as well as with existing ones, in a joint effort to analyze and solve the problem. As a direct consequence of these efforts, and by comparing the occurrence of problems related to gear boxes, several producers pooled resources to find out why some of NEG Micon's wind turbines had broken down. This was crucial, because it had the potential to destroy politicians' confidence in the competencies of the wind turbine manufacturers and with it the reputation of the industry vis-à-vis alternative energy producers. As explained by CC Jensen:

> *We have a dialogue with our customers, and usually we suggest that we participate in solving the problem at their facilities. Once the problem is identified, we would like to come up with a solution and to test it in the field. We then select some turbines jointly and install our equipment in the turbines. We analyse the data output together with our clients' engineers…we have worked like that for five years now…. Together with engineers from Micon, Bonus and Vestas we all participated in the analysis of what*

> *went wrong in the gear box (with the Micon turbine), and we were not the only team working on this. We tried it from the oil side, analyzing the oil particles.*
>
> [Ulrich Ritsing, General Manager, CC Jensen]

Other meetings have a less dramatic background and are aimed at employing new solutions and technologies. The annual energy fairs in Europe and the US are a frequent venue for these meetings. Typically, development engineers use the workshops at these venues to exchange ideas. A case in point is a science workshop organised by Densit at a wind energy trade fair in Germany. As explained by a sales executive in Densit:

> *After we had participated in the construction of Horns Rev, I was at a fair in Hamburg and was contacted by the Danish Embassy there. They asked whether we could conduct a seminar on these matters. I and A2SEA [a company specialized in offshore construction] decided to give it a go…we wanted representation from a broad group of companies responsible for different parts of the construction…More than 100 potential customers with offshore contracts participated in our session…we had them for a whole day in Bremerhafen. During the morning, each of the firms we had invited to give a talk made a presentation…Development and sales shade into each other. I do not consider myself to be a sales person in the conventional meaning of this word.*
>
> [Anders Møller, Chief Sales Executive, Densit]

Appropriation of individual firm benefits

The interviews also focussed on how the firms ensured that they were able to reap the benefits from their deployment of resources into development efforts. In all cases, the interviewers were told that in the wind turbine industry it was customary to provide assistance for customers' technology development efforts, and that there were usually no formal agreements protecting intellectual property rights. Rather, subcontractors had clear expectations that their payback would be in the form of a status as preferred subcontractor. As explained by CC Jensen:

At the moment we do not charge anything for the knowledge we deliver and we are not guaranteed anything…it's more of a moral binding than anything else…this entails vulnerability and is also something we discuss a lot internally.

[Ulrich Ritsing, General Manager, CC Jensen]

Obtaining patents may be one way for an individual firm to capitalise on the knowledge contributed to joint efforts with customers. However, as pointed out earlier, there are relatively few patents in the industry, and the process of using patents is regarded with a lot of scepticism, since it can lead to segregation and a lose-lose situation for all actors involved. Individual appropriation is seen as an attempt to profit on shared competencies, and may lead to collective sanctioning in the form of exclusion from future learning possibilities and a damaged reputation of the firm concerned. As pointed out by Densit, taking out patents and licensing these to specific customers under exclusive rights would probably make some customers abandon the densit grout solutions for anchoring offshore wind turbine plants on the sea bed. Likewise, VBE says that patenting would preclude them from future collaboration with important customers, who may invent around the patents anyway.

LM Glasfiber is an interesting exception to the observed trend among subcontractors regarding patenting, since they do have a few patents. In this sense the company resembles the turbine manufacturers, which also have a moderate – and drastically increasing - number of patents. LM Glasfiber also shares a sole focus on wind turbines with the turbine manufacturers, whereas most subcontractors to the industry are active in other industries as well. And, like the turbine manufacturers, LM Glasfiber benefits from its subcontractors being active in several industries. For example, the company can keep new knowledge developed jointly with subcontractors from its competitors through an agreement with subcontractors that restricts them to selling products based on the new knowledge to customers in other industries than the wind turbine industry. This enables both the blade manufacturer and the subcontractors to reap the benefits of the collaboration. Similar types of relations with subcontractors active in several industries can be found in the automobile industry.

The ability to use the knowledge obtained from wind turbine activities in complementary industries is thus an important mechanism for continued openness among subcontractors in the wind turbine industry. As shown in table 1 above, all the case firms have activities in complementary industries, or at least developed their skills in these industries; and the knowledge obtained from solving specific problems in wind turbine plants has proven useful in other situations as well. Table 2 gives an overview of some of the examples that were found during the data collection. The table also includes examples collected from informal talks with other firms than the case firms and from archival data collection.

Table 2: Examples of knowledge brokerage across industries involving the wind turbine industry either as recipient or sender

Example	Company	Related industry
Development of a heating system for offline oil filter systems in offshore wind turbines in order to ensure fluidity of oil under extreme weather conditions	CC Jensen	Offline filters for engines in the marine industry
Development of anchoring systems for the foundation of wind turbines on the sea bed	Densit	Anchoring systems for oil rigs and oil pipelines
PLC controls for sensory equipment to ensure the correct pitching of wind turbine blades to the wind	Cotas Computer Technology	PLC control systems for washing machines and industrial refrigerators
Painting systems to prevent corrosion of wind turbine towers and reduce maintenance costs	Hempel	Painting systems for the offshore petroleum industry

Although there seems to be general agreement that individual attempts to enforce intellectual property rights come at a cost to all involved, the interview firms had strong concerns about this. As the wind turbine industry becomes increasingly concentrated, this may lead to greater use of formal IP strategies. The tendency is for companies investing more heavily in becoming specialized suppliers to the wind turbine industry to look for new ways to protect their knowledge investments. Hence, LM Glasfiber has initiated a more formalized policy for exchanging knowledge.

> *Working with our customers, we have become much more secretive with respect to explaining our production processes – many of them are thinking about or have already started up their own production of blades – we do not want to give them a head start. They must fight their own battles.*
>
> [Anders Christensen, General Manager, LM Glasfiber]

Similarly, since its experiences from losing a large customer and trying to regain the knowledge lost, AVN is both investing heavily in specialized development equipment for the wind turbine industry and patenting its new hydraulic system. Patenting thus appears to go hand in hand with a more narrow industry or market focus among subcontractors to the wind turbine industry.

5. Analysis

Studying the innovation practices of subcontractors in the wind turbine industry has given us insights into the organisation of innovation activities and appropriation of firm benefits. These have important implications not only for studying innovation practices and how they are affected by technological regimes, but also for studies of the local embeddedness of innovation in particular industrial districts. This analysis poses a challenge to the modularised versus systemic architecture approach, which seems to be a too sweeping dichotomy for describing what can better be perceived as an array of different practices for balancing innovation contribution with the ability of individual firms to appropriate innovation benefits.

The Chesbrough/Teece/Kusunoki framework in particular is a too narrow conception of the market for technology, since it overlooks the fact that, while the technologies offered by individual contributors are applicable in a wide range of industries, they are not necessarily complementary in nature. Here, the concept of market heterogeneity and seminal insights from Richardson (1972) can be used as a theoretical basis for the critique and to provide a better framework for the activities.

First, the notion of technological systems as a way of describing the technological bindings and trajectories of a specific group of business actors may be less useful in the empirical world of practitioners than assumed in the theoretical world of academics. As pointed out by Coombs et al. (2003), the dichotomy of modular versus systemic innovation processes does not square neatly with empirical realities. This agrees with Astley & Van de Ven (1983), who point out that such concepts are vested in an idealist world and thus bring with them a particular ontology and epistemology. Hence, one way of looking through a set of theoretical lenses also means overlooking alternative interpretations of the same phenomenon. Moreover, the deterministic flavour of the product architecture framework fits poorly with entrepreneurial acts of jockeying for position in a never-ending game of dividing work and setting boundaries between one actor’s activities and another’s. As pointed out by Thorelli (1986), networks do not represent neat systems based on an overall logic of the division of work. Rather, they are comprised of actors, each following their own territorial logic and striving to position themselves vis-à-vis other suppliers. Thus, seen from a micro point of view, the notion of technological systems, such as modular and integrated systems, seems less clear than when looking at the broader perspective. In this case, the technological contributions to the development of wind turbine parks were seen as systemic and interdependent. Few standards, if any, were found for describing the interfaces between the constituent components of the system, and most of the interviewed actors referred to wind turbines as integrated systems to which their components fit, reflecting an interdependent or systems-based holistic pattern of thinking. At the same time, however, interdependency is not associated with a tight coupling of the constituent elements, but reflects more a loosely coupled system (Weick, 1976). Rather than role-taking, i.e. subsuming to a role in the overall system as cogs in a complex machinery, actors engage in what may be called role-playing, i.e. processes of mutual adjustment where each actor knows the vantage point of the constituent elements of the wind turbine system well enough to be able to anticipate how activities affect the overall system. Thus, from the point of view of the subcontractors, the product categorization of the product architecture did not square easily with the empirical realities.

The question that remains is: How do companies in organisational settings, which Chesbrough and Kusunoki (2001) would describe as misaligned to the nature of the technology, capture innovative dividends from their contributions? As pointed out earlier, few activities of subcontractors in the wind turbine industry are aimed at capturing and harvesting IP rights. Rather, the norm reflected by the interviewed companies was that such activities would quickly isolate the company from any future learning possibilities, since it would be seen as seeking to reap the benefits of what is regarded as a semi-open shared good by the actors involved. Customs of reciprocal cooperation play an important part by making exchange possible which might otherwise be blocked, due to the risk of losing appropriation possibilities at a later state. Ignoring established norms not only makes partners withdraw, but can also damage the reputation of the firm concerned. Hence, strategizing à la Chesbrough may quickly spell disaster to any company trying to act integratively, since the market provides a system for the collective sanctioning of opportunistic behaviour, which may safeguard even risky forms of cooperation (Dei Ottati, 1994).

The most convincing explanation is that the Chesbrough/Teece/Kusunoki framework builds on a too narrow range of implicit assumptions of market homogeneity and technological determinism, at least in the Danish context of subcontractors to the wind turbine industry. Building on the first point, the role of technological contributions and how they fit into the individual and strategic horizons of the contributing firms reflect what has been described as a heterogeneous rather than a homogeneous market construct. The purpose of any market-based industrial organisation is to coordinate or match resources to demand. This is certainly the case for resources such as technology. However, as demand and resources are often heterogeneous in nature, resources are multidimensional (Hagg & Johanson, 1983). This means that, while technological resources can be used in a variety of contexts to solve similar problems, they do not need to be complementary to a specific set of other resources (Richardson, 1972). For the individual firm this means that the appropriation of benefits from technological contributions does not need to take place in the same context as where they are first made. Rather, the ability to redeploy competencies in a range of industries can be seen as a core capability for achieving dynamic efficiency, as compared with static economic efficiency (Richardson, 2003). For instance, in the case of Densit and CC Jensen, the ability to draw on, as well as contribute to, knowledge and technology development in other industries was a core aspect of their appropriation strategy. Thus, these companies saw the possibilities for maximizing continuous learning and functioning as a knowledge broker across industries as a core feature in their strategic positioning. The same factors were at play for the subcontractors to LM Glasfiber. The ability to re-use and renew knowledge across industrial sectors plays a decisive role in understanding the underlying dynamics of distributed innovation activities in the wind turbine industry. The Danish national innovation system is characterized by a large number of SMEs, where a fine-grained and flexible division of labour allows subcontractors to participate in different industries (Kristensen, 1995; Sabel, 1987). Investigations show that buyers rely strongly on their ability to involve suppliers in innovation activities (Madsen, 1999). In line with these buyer expectations, a crucial prerequisite for subcontractors is to be able to act as knowledge brokers across multiple industrial settings and be involved in continuous processes of learning-by-doing in order to maintain their competitive position within these industries. Given these structural conditions, the ability to preserve learning relationships becomes more important than capitalizing directly on knowledge gained through strategies for preserving and reaping IP rights.

Similarly, the conditions assumed obligatory for a decentralised form of coordination to occur can also be challenged. Hence, Chesbrough & Kusunoki (2001) claim that it is the presence of established standards that "permits multiple firms to compete at each level of technology" (cf. p.

206), allowing markets for technological inputs to function efficiently. Implicit here is that markets for technologies can be carved out to meet the “commodity-like” requirement of homogeneous markets in order to function efficiently. However, there is intense rivalry among suppliers of wind turbine components to become the dominant supplier of technological designs, even though the technologies are less than comparable. The point here is that different technologies may fulfil similar needs, just as similar wants may be linked to quite diverse needs across a diverse range of industries. This point is illustrated by Densit, who seeks to position itself in the wind turbine industry using one particular technological solution based on technical cement for anchoring offshore wind turbine parks – in stark contrast with two other systems. At the same time, Densit’s solution may find uses in different industrial settings, where the solutions from competing suppliers are irrelevant. Our results thus indicate that at low degree of assets specificity of technology inputs is an important part of the explanation to why the distributed organisation of systemic innovation activities is *not* a paradox. Rather this appears to have been a very fruitful mode of organization playing an important role for the Danish wind turbine industry’s ability to reach its pinnacle in the form of a dominant position on the world market. The findings are in accordance with previous findings by Garud and Kumaraswamy (1995) that firms operating in systemic environments have to design technological systems to yield and exploit economics of substitution.

6. Implications for management and academia

As the above analysis has shown, the relation between firm organisation and the ability to appropriate the benefits from innovation is more complex than assumed in existing literature on distributed innovation. Previous research has suggested a dichotomy of organisational practices depending on the systemic character of innovative activities. According to this dichotomy, distributed production systems are ill-suited to systemic innovation processes, at least from an appropriability point of view, because the distributedness of activities undermines the possibilities for control and coordination of interfaces. However, coordination may also be achieved among agents whose actions are guided by customs and the implications for reputation as a valuable collaboration partner. Especially in a learning economy, where the focus is on the ability to exchange and develop knowledge, coordination through collaboration may come to play an increasingly important role.

The dilemma between society’s interest in sharing and diffusing knowledge, and the individual firm’s interest in protecting knowledge in order to reap the economic benefits from investments in knowledge creation, is classical. But the insights from the Danish wind industry presented here suggest that individual firms may also see advantages in sharing knowledge. As long as the market is heterogeneous enough to ensure that technological resources can be applied to solve similar problems in a variety of contexts, the single firm will be able to appropriate benefits from technological contributions through a redeployment of competencies in a range of industries. This may be interpreted both as a core capability for achieving dynamic efficiency and as a system-inherent capability vested in the distributed nature of activities across a range of different industrial settings, which is typical of most subcontracting. The diversification of activities makes the exchange of knowledge less risky than standard explanations in the literature would have us believe.

As value creation becomes increasingly dependent on learning and the development of new knowledge, it is crucial to improve our understanding of the complexity of the appropriability issue in relation to the possibilities for engaging in knowledge-producing interactions. This poses new challenges for management, since corporate strategy must take into account how to support the ability to enter into the right kinds of knowledge-creating interactions, and how to maximise the scope for appropriating the benefits in different contexts. This thus calls for openness in two dimensions: openness towards collaboration partners; and openness towards alternative uses of newly developed knowledge, i.e. developing new knowledge with a heterogeneous rather than homogenous demand structure in mind.

The finding that firms can be overly protective of their innovations agrees with the finding of Laursen and Salter (2005) that an overemphasis on appropriability can have detrimental consequences for innovation performance. In line with the case studies in the present context, Laursen and Salter suggest that firms which become obsessed with secrecy may limit their opportunities to collaborate and trade knowledge informally with suppliers, customers and competitors, thereby isolating themselves from the rest of society in the vain pursuit of full protection.

These findings not only have managerial implications, but also point to the need for broadening the discussion to include the socio-economic and institutional conditions for certain types of appropriability. An interesting next step would be to compare the appropriability conditions of the Danish wind turbine industry with a similar industry in another country in order to shed light on how strategies can vary between industries and national settings, and also to find indications of the underlying determinants of why certain types of appropriability regimes emerge (Whitley, 1992). Another issue for further research is the degree to which the dominance of different appropriability regimes changes over technology and industry life cycles independently of the systemic character of innovation activities (see Andersen and Drejer, 2005 for a discussion of this).

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