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Relational Discontinuities in the Global Wind Turbine Production

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Abstract

The global wind turbine industry experiences a structural change since 2007. This change consists of a demise of old market leaders and entry of new firms. This disruption resembles a technological discontinuity, yet it seems to be induced by new and modular ways to organize production. We define modular production as ?relational discontinuity?, as it changes the relation between product components and between manufacturers and suppliers. The industry was shaped by a dominant model of production that consists of vertically integrated firms and long-term and exclusive supplier relations till 2006. New firms introduce modular production into the industry, which disrupts the previously dominant form of production since 2007. This discontinuity especially negatively affects those firms that were deeply embedded in the previously dominant system. We conclude the industry is still in transition and has not yet established a new dominant form of production.

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Introduction

Industries are regularly disrupted by technological discontinuities. Indicators on the industry level are new entries, emergence of new and demise of old market leaders (Anderson and Tushman 1990, Christensen and Rosenbloom 1995). Since 2007, the global wind turbine generator (WTG) industry exhibits such a pattern. The global market share of top ten manufacturers steadily declined from 94,9% (Btm 2010) in 2006 to 68% in 2013 (based on MAKE Consulting; north American WINDPOWER 2014). Once dominating firms like Vestas, despite still leaders in the market, lost half of their market share. Additionally, new firms appeared among the top producers, which in 2006 only were a few years old like Goldwind (1998), just formed like United Power (2006) or did not even exist like Envision (2007).

While the industry exhibits the pattern of a technological discontinuity, this pattern does not seem to be caused by a new technology. Indeed, there are such technology induced developments in the wind turbine industry. The offshore wind energy industry also exhibit new entries and market leaders. However, offshore wind turbine production only represented 2% of yearly installed capacity in 2012 (Gwec 2013) and major offshore turbine manufacturers like Areva do not appear among global top manufacturers.

Additionally, it seems that especially European companies were affected by this discontinuity. Between 2006 and 2009, market shares of European top ten manufacturers dropped from 75,9% to 39,8% and remained on this level. While these developments are surely connected to the emergence of a domestic wind turbine Industry in China, its effects seem to be more profound. Indeed, Chinese producers introduced new modular forms of production that are adopted by established producers (Lema et al. 2013).

Therefore, we argue that the observed change in industry structure is not only caused by the emergence of new domestic industries in emerging markets. Instead, these new firms introduce new modular ways of production and supplier relations. As modular production changes the relations between product components as well as between suppliers and manufacturers, we term this a *relational discontinuity*. The discontinuity is caused by the different capabilities of established firms to adjust to this change.

The paper is structured as follows. The next chapter describes how technological discontinuities disrupt industries as they change the environment in which innovative activities are coordinated (Anderson and Tushman 1990, Christensen and Rosenbloom 1995). The third section investigates the processes leading to modular forms of production (Baldwin and Clark 1997, Sturgeon 2002, Gereffi et al. 2005). The fourth section describes methods and data. The fifth section describes the industry structure in 2006 and analyses global developments in which the structural change of the industry takes place. The sixth section describes how a discontinuity disrupts the industry from 2007 on and how the dominant mode of production organization changes till 2013. The seventh section concludes.

Technological Discontinuities

Models of industry evolution like product (Abernathy and Utterback 1978) or industry life cycles (Klepper 1996) propose a clear sequence of spatial evolution driven by subsequent regimes of radical, incremental and process innovation (Audretsch and Feldman 1996; Bünstorf and Klepper 2009; Heebels and Boschma 2011). However, industry and technology studies show that this general pattern is often disrupted by technological discontinuities (Tushman and Anderson 1986). Anderson and Tushman (1990, 604) define a discontinuity "innovations that dramatically advance an industry's price vs. performance frontier". Technological discontinuities are not necessarily radical. They often comprise only few changes in the design of a product, the product architecture or a production process, which yet describe major technological advances (Henderson and Clark 1990).

While there are, thus, many different forms of technological discontinuities, they have in common that they work in a way which established firms often have difficulties to cope with (Utterback 1994). In this respect, Tushman and Anderson (1986) distinguish between competence enhancing and competence destroying discontinuities. Competence-destroying discontinuities require new skills and knowledge to master the development as well as the production of the new technology. Competence enhancing discontinuities build upon existing competencies. Depending on the quality of the discontinuity, it leads to a wave of new entries, the demise of former market leaders, exits of established firms and in doing so to a change of the overall industry structure (Anderson and Tushman 1990; Murmann and Frenken 2006).

Murmann and Frenken (2006) argue that technological discontinuities especially take place in industries whose products are shaped by a common dominant design, i.e. a technological design like the IBM architecture for PCs that has a market share of more than 50%. A change of this dominant design would affect large parts of the industry and thus might have an impact like that of a radical innovation, without being radical itself. Henderson and Clark (1990) further suggest that especially architectural innovations, i.e. "innovation that change the architecture of a product without changing its components" (Henderson and Clark 1990, 9), have such an effect on industries. Examples for products comprising the same components but different architectures are desktop PCs and notebooks. Changes in the product architecture alter the relations between these components, which again require new ways of coordination of production and innovation processes (Murmann and Frenken 2006).

Established firms have difficulties to cope with these changes, as their organizational structure is established with the aim to generate innovation in the single components of a product, yet coping with architectural innovation also requires a change in governance of relations (Henderson and Clark 1990, Christensen and Rosenbloom 1995). Garud and Munir (2008) for example described how the changes in firm structure and boundaries that accompanied the development and production of Polaroid's SX-70 camera also affected relations to customers, suppliers, competitors and vendors. Therefore, it is not the change of technology as an artifact that has these often radical effects on industry structures. Instead, these radical effects result from changes in coordination of firm activities that accompany these changes.

Modularity

Technological change can result in a discontinuity, as industry relations have to adjust to the new product architecture or a new production process (Murmann and Frenken 2006; Garud and Munir 2008). Yet, this change of industry relations can occur without the impact of a particular technology. Modularization describes such a relational change.

Product and Supply Chain Modularity

Campagnolo and Camuffo (2010) distinguish between modularization on the product level, i.e. a modular product design, and modularization on the manufacturing level, i.e. in- house or outsourced manufacturing. A *modular* product consists of components that are interchangeable without adjustments in other components (Baldwin and Clark 1997). Development here focuses on the definition of standardized interfaces between the components within the product architecture. These interfaces enable a minimum of interactions between the components or modules within a product (Gershenson et al. 2003). Components therefore can be easily exchanged, without affecting other components (Mikkola and Gassmann 2003).

Modularity on the product level resembles platform strategies. The most apparent commonality is "the conservation or reuse of a core component to achieve economies of scale while reducing the cost of creating a wide variety of complementary components" (Baldwin and Woodard 2008, 3). The architecture of a platform, which specifies the functions and the boundaries of modules, is made up of fixed core components that remain unchanged over time and peripheral components that can be varied. The core components can either be designed to be unchanged or they simply outlive the peripheral components, since they represent the longest-lived part in the product. In addition to product modularity, platform strategies therefore include a "detailed specified product architecture" (Voordijk et al. 2006, 613)

The required definition of interfaces to standardize the relations between components takes place via codification of previously often tacit knowledge. Commonly accepted standards facilitate this process, as the codification process can refer to a piece of already codified knowledge (Cowan and Foray 1997). Sturgeon (2003), for example, describes standards as a driver behind value chain modularization in the Silicon Valley. Standards therefore facilitate interchangeability and interoperability of products and services (Nix and Bassolino 2013).

As mentioned before, the enforcement of generally accepted standards increasingly resolves traditional relationships (Sturgeon 2003) as they “simplify interactions by reducing component variation and by unifying component, product, and process specifications” (Gereffi et al. 2005, 86).

In addition to the product, modularization extends also to the organizational level. It is generally assumed that the structure of a product corresponds with the structure of organizations (MacCormack et al 2012). A modular product architecture is therefore often accompanied by a modular supply chain organization, described by outsourcing of previously internally produced components and broadening of supplier base (Campagnolo and Camuffo 2010).

In contrast to market based exchange, modularization entails knowledge exchanges about the requirements of the component. Compared to long-term relations, where the supplier accumulate implicit knowledge about the expectations of the manufacturer, and the manufacturer about the capabilities of the supplier, standardized interfaces between components disembed them from their social, organizational and spatial context (Sturgeon 2003). This disembedding via codification facilitates outsourcing and enables the exchange of complex information “with little explicit coordination” (Gereffi et al. 2005, 86), thereby lowering costs of switching suppliers and making suppliers and lead firms mutually substitutable (Sturgeon 2003). In both cases, modularization is often accompanied by a shift in responsibility to suppliers, which again results in increased R&D efforts on the supplier level (Ro et al. 2007).

Knowledge and Competences in the Context of Modularization

Modularization depends not solely on strategic decisions, but also on industry structures, supplier base, product characteristics, and firms’ capabilities (Fixson et al. 2005). Nevertheless, the literature indicates some regularities in modularization. Vertically integrated manufacturers of non-modular products can follow three different paths to product and organizational modularization (Campagnolo and Camuffo 2010). First, firms modularize products and later outsource components or broaden their supplier base. This path was for example followed by the information technologies industry in the Silicon Valley (Sturgeon 2003). Second, lead firms already have a broad supplier base, but start to modularize the product. Third, firms implement outsourcing and product modularization strategies simultaneously.

These paths to modularization affect the routines of a firm. On the product level, to transform an integrated towards a modular product requires elaborating specifications for standardized interfaces. This process might entail new component functions or altering the ways components interact and in doing so even alter the product architecture. Therefore, modularization of a product requires learning, experimentation and the establishment of new routines related to the product, its design and production (Baldwin and Clark 1994).

On the organizational level, modularization changes the ways firms organize their production and supply chains. For example, in production systems shaped by long-term relations, knowledge about components, mutual expectation and organizing of production is embedded within these relations. Codification of this embedded knowledge requires the implementation of new routines to continuously codify this knowledge (Sturgeon 2003). In addition to competencies on codification processes, modular production systems are shaped by high degrees of volatility, due to a spatially dispersed, highly flexible and broad supplier base. The organization of this increased complexity requires other competencies than for example a production system shaped by stable long term relations. Supply chain management and global sourcing become more important and new forms of control mechanisms (e.g. quality standards) and assessments of suppliers have to be implemented.

Modularization can have disruptive effects on industries as these two dimensions of modularization refer to those changes that are, beside a new product or a new process, considered to be crucial sources of discontinuities. First, modularization changes the product architecture (Henderson and Clark 1990). Second, modularization changes the relational setting of a firm (Christensen and Rosenbloom 1995).

However, the degree to which modularization works disruptive depends on firm competencies. When firms already applied forms of modularization on the organizational or product level, the effects are less competence destroying compared to a firm without these capabilities. Therefore, we expect that those firms have less difficulties that are closer to it, i.e. for example already vertically disintegrated, broader supplier base or platform strategies.

Methods and Data

While technological discontinuities have their disruptive effects as firms have difficulties to change their innovation relations towards a new dominant technology, modularization affects the relations itself. It affects relations on several levels: on the product level as it changes the relations between components, on the firm level as it affects what is produced inside the firm and outside the firm, on the inter-firm level as it changes established relations to suppliers.

There are several indicators to measure the introduction of modular forms. An indicator on the product level is the introduction of modular designs or platform strategies (Baldwin and Clark 1997, Sturgeon 2002). Indicators on the level of inter-firm relations are the vertical disintegration and outsourcing of components previously produced in-house and the broadening of supplier base.

The sources for this data comprise of business and annual reports, Interview data, press releases and Interviews in Industry Journals, were reference was made to either specific suppliers or their number per component. Modularization on the product level in the form of platform strategies and introduction of a modular product design is usually announced in business reports. The same accounts for changes in the vertical integration of manufacturers, i.e. the out- or in-sourcing of particular component production as well as for sourcing strategies. We use information for blades, generator, gearbox, and tower, which represent the core components of a WTG (see Kammer 2011; Sommer 2015).

We use these indicators to analyze the change of top ten producers. The global WTG industry is shaped by large manufacturers. Top ten producers in some years cover close to 100% of global production (BTM 2005). Analyzing global top ten producers therefore gave a good indication of the change of the whole industry. Changing composition of top ten producers and changing degrees of vertical integration and modularization strategies allows delimiting firms with different production models and in doing so respective global shares. Information about the market shares of top ten producers are announced by consulting firms like BTM or MAKE.

We use two indicators for knowledge codification. The first is licenses. Via licenses, knowledge on turbine design is transferred from one firm to another. Licenses are a codified form of knowledge. The licensing process often includes teaching activities which enable the licensee to produce a turbine according to the license. The second is the implementation of global standards. We use standards implemented by the International Electrotechnical Commission (IEC).

Our analysis is inherently dynamic. Therefore we focus on the temporal change of certain patterns and dynamics. First, we expect a dominant form of production that is replaced by a modular form of production. Second, we expect that modular forms are introduced by new entrants and established ones adjust to this form. Third, we expect especially those established ones that are deeply intertwined into a previous dominant production model to experience difficulties to adjust to new and modular forms of production.

Development of the Global Industry

This section describes the environment and the longitudinal development of the industry. First, it describes the industry structure and defines the quality and time scale of the disruption. Second, it describes the development of national and global markets during the time of the disruption. Third, it describes the temporal evolution of technological designs to account for technological developments during that time.

Development of the Industry Structure

A discontinuity is marked by a change in market structure, indicated by the demise of old leaders and the entry of new firms. Figure 1 describes the market share of top ten and top five producers during that time. Since 2006, the global wind energy industry was close to an oligopoly, with top ten producers supplying nearly 100% of the global market. Since 2007 their market shares declined. This pattern indicates that new firms entering the industry manage to grow and win market shares from established producers. This Figure shows that the year 2006 is a reference date for a change in industry structure.

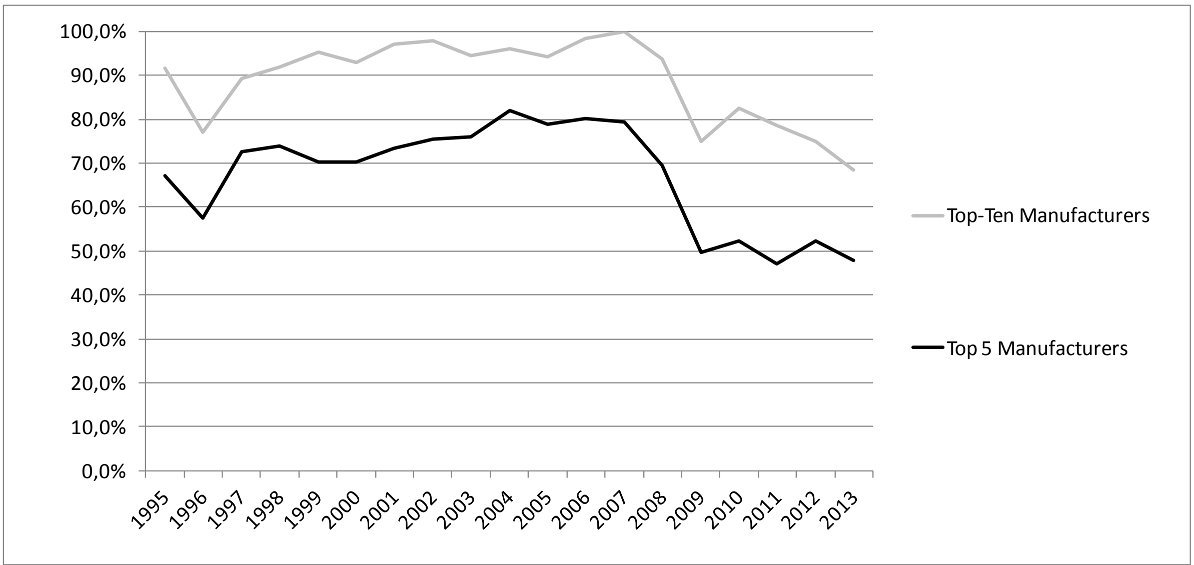

Figure 1: Cumulated Market Share of Global Top Ten/ Top Five Manufacturers (own calculations, based on data by BTM, MAKE and Bloomberg)

The following Table 1 shows the top 10 producers for 2006, with a market share of nearly 100%, and the top 15 producers of 2013, with only about 80% of the global market. The age structure differs considerably. In 2006, the average firm age was 17,3 years. The industry in 2013 includes many of the firms that were also among top manufacturers in 2006, which of course became seven years older till then. However, the average age of the firms declined to 16,3 years due to the many new entrants. These new entrants open up the oligopolistic industry structure of 2006 and decrease the average firm age in the industry, indicating a change in the industry that affects its structure at least from the year 2007 on.

	2006	2013
Vestas (DK)	1975	1975
Gamesa (ES)	1994	1994
Enercon (DE)	1984	1984
Siemens (DK)	1980	1980
Nordex (DE)	1985	1985
REpower (DE)	1991	
Acciona (ES)	1989	
GE Energy (US)	1996	1996
Suzlon (IN)	1995	1995
Goldwind (CN)	1998	1998
United Power		2006
Mingyang (CN)		2006
XEMC (CN)		2007
Envision (CN)		2007
DEC (CN)		2004
Sinovel (CN)		2006
Sewind (CN)		2006
ave. Age	**17,3**	**16,3**

Table 1: Age of Largest Manufacturers 2006 and 2013

Development of Global Markets

The structural change of the industry took place during a phase of strong growth. While the global annual installed wind capacity grew steadily from 1996 (around 1 GW) to 2004 (around 8 GW), it increased significantly from 2005 (around 11 GW) on. In 2007, for the first time more than 20 GW were installed within one year. The 30 GW mark was exceeded in 2009 and already in 2011 more than 40 GW have been installed. A downturn in 2013 (35,5 GW) was the result of changing regulations in the US market. As the production tax credit for this year was not extended before December 2012 it declined from 12 GW to 1 GW. This downturn was again followed by new record installations of around 51,5 GW in 2014.

Although this increase was influenced especially by the emergence and strong growth of the Chinese market[1], the markets were not isolated. The structural change rather took place in a phase in which companies from different countries increasingly competed in the same markets. Figure 2 illustrates the shares and numbers of domestic and foreign manufacturers on the three largest markets, China, the US and Germany from 2004 to 2012, respective 2013. The German market remained quite stable regarding yearly installed capacity. In contrast, the Chinese market showed strong growth, while in the US growth was interrupted by declines in 2010 and 2013.

China had a quite internationalized market in 2004, when foreign manufacturers accounted for nearly 80% of the installed capacity and for more than half of the active manufacturers. These shares declined considerably during the emergence of a domestic industry till 2010.

The US market exhibited a different growth pattern. Like in China, the installed capacity grew strongly from 2004 till 2012. Yet, with the exception of 2005 and 2011, US and European manufacturers had rather even shares of over 40%, while Asian producers provided the remaining share.

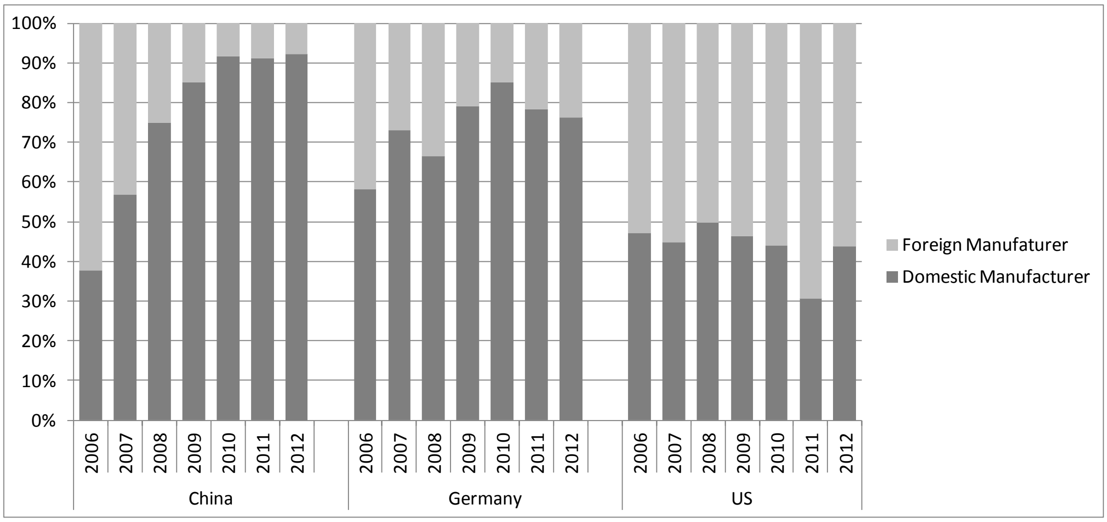

Figure 2: Market Shares of Domestic and Foreign Manufacturers in the wind turbine markets of China, Germany and the US (based on country statistics by CWEA, AWEA and DEWI as well as further statistical sources)

[1] 2008 (6,1 GW), 2009 (13,7 GW), 2010 (19 GW), 2011 (17,6 GW), 2012 (13,2 GW), 2013 (16,1 GW), 2014 (23,2 GW)

This picture of domestic and foreign market shares is, however, somewhat limited. The growing share of domestic manufacturers in China for example is accompanied by a respective growth in number of active firms, while the number of foreign firms remained stable until 2009 and declined afterwards.

In the US, however, although the share of foreign manufacturers remained quite stable, the number of firms supplying turbines considerably changed. While the number of US companies did barely change, the number of European and Asian manufacturers strongly increased, especially since 2008.

The number of active firms in the larger markets and especially the number of manufacturers from different countries in the US indicate an increase in global competition, as manufacturers more and more compete in the same markets. The German market remained quite stable regarding the number of active manufacturers and seems to be rather closed for new entrants.

China	2006	2007	2008	2009	2010	2011	2012	2013
Number of manufacturers*	**8**	**17**	**15**	**12**	**10**	**20**	**19**	**18**
thereof Asian	3	13	11	7	8	17	16	15
thereof European	4	3	3	4	2	2	2	2
thereof North American	1	1	1	1	0	1	1	1
Germany	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Number of manufacturers*	**8**	**6**	**7**	**7**	**7**	**5**	**7**	**8**
thereof European	7	6	5	6	7	5	6	7
thereof Asian	0	0	1***	0	0	0	1***	0
thereof North American	1	0	1	1	0	0	0	1
US	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Number of manufacturers**	**6**	**8**	**16**	**21**	**18**	**24**	**27**	**7**
thereof North American	1	2	5	5	5	5	4	-
thereof European	3	4	7	10	9	9	13	-
thereof Asian	2	2	4	6	4	10	10	-

* Numbers of Manufacturers installing WTG during respective years according to country specific market shares; Number and origin of “others” unknown

** Numbers of Manufacturers installing WTG during respective years according to AWEA

*** Vensys: bought by Goldwind in 2008. Thus categorized as Asian Manufacturer, although company has its origin in Germany and the Technology was developed by Vensys.

Table 2: Number of Manufacturers installing turbines in China, Germany and the US per year (based on country statistics by CWEA, AWEA and DEWI as well as further statistical sources)

During the international expansion of the wind energy markets several manufacturers set up international manufacturing branches. Siemens, for example already in 2007 (expanded in 2008) established a blade manufacturing in Fort Madison, Iowa, followed by a nacelle production in Hutchinson, Kansas in 2010. In the same year, the first manufacturing facility in China (Shanghai) was set up to produce blades. Vestas has a "regionalized manufacturing footprint" with sites in the USA, Brazil, Spain, Denmark, Germany, India and China. Enercon, Nordex, GE Energy or Gamesa also set up international manufacturing facilities.

The trend to be close to the markets also becomes apparent in Brazil, where several WTG-manufacturers - such as IMPSA (2008), Alstom (2011), Gamesa (2011), GE Wind (2011), Vestas (2011), Suzlon (2012) or Acciona (2013) - and international as well as local component manufacturers - e.g. Aeris Energy (2010), Gestamp (2010) or LM Wind Power (2013) - set up facilities[2].

A different approach to internationalize their manufacturing footprint was adopted by Chinese manufacturers. While Goldwind accessed a German manufacturing facility through its entry as a major shareholder in Vensys in 2008, XEMC acquired Darwind Holding BV in the Netherlands in 2009. Mingyang again took a majority stake in manufacturer Global Wind Power (GWP) from India in 2013, to assemble turbines in the country, while supplying the components from China.

[2] Due to local content requirements the location in Brazil - as the fastest growing emerging market in the industry - is indispensable to participate in funding by the BNDES.

Rank 2013	Company	Country	Europe (outside home market)			Americas			Asia		
			Location	Established	Closed	Location	Established	Closed	Location	Established	Closed
1	Vestas	DK	Taranto, IT (2 factories)	1998	2013	Windsor, US	2008	-	Tianjin, CN (3 factories)	2006 - 2009	-
			Lauchhammer, DE	2002	-	Pueblo, US	2010	-	Chennai, IN		-
			Villadangos del Páramo, ES	2006	-	Brighton, US (2 factories)	2010 - 2011		Hohhot, CN		2012
			Daimiel, ES	2008	-	Maracanaú, BR	Q4 2011	-			
			Isle of Wight, UK		2009						
			Viverio - Lugo, ES		-						
			Lübeck, DE		-						
2	Goldwind	CN	Neunkirchen, DE	2008	-						
3	Enercon	DE	Malmö, SE	2000	-	Matane, CA	2011	-			
			Turkey	2002	-	Brazil (mobile tower factory)	2011	-			
			Viana do Castelo, PT	2008	-	Sorocaba, BR	1996	-			
			Lanheses, PT	2009	-						
			France	2011	-						
			Zurndorf, AT	2013	-						
4	Siemens	DE	Brande, DK	2004	-	Fort Madison, US	2007	-	Shanghai, CN	2010	-
			Aalborg, DK	2005	-	Hutchinson, US	2010	-			
5	Suzlon	IN				Maracanaú, BR	2012	-			
						Pipestone, US		-			
6	GE Energy	US	Salzbergen, DE		-				Shenyang, CN	2006	-
									Pune, IN	2011	-
7	Gamesa	ES				Camaçari, BR	2011	-	Tianjin, CN (5 factories)	2006 - 2011	-
									Chennai, IN	2010	-
									Jilin, CN	2011	-
									Gujarat, IN	2012	-
9	Mingyang	CN							Silvassa, IN	2013	-
10	Nordex	DE				Jonesboro, US	2010	2014	Yinchuan, CN	2006	-
									Dongying, CN	2007	2012

Table 3: International manufacturing units of the Top 15 WTG-Manufacturers (own data, based on information from corporate websites, industry magazines and other press releases)

Table 4, furthermore shows that turbine manufacturers are not only increasingly competing in the same geographic markets, but also in the same market segments, described by turbine size. While on average the European and US manufactures introduced the first category (≥ 1.5 MW) around 10 years prior to their Chinese counterparts, this time span decreased to eight (≥ 2.0 MW) and less than five years (≥ 2.5 MW) respectively. The current standard sizes of ≥ 3.0 MW were introduced on average less than 1 year apart.

TOP 10 (2013)	Origin	≥ 1.5 MW	≥ 2.0 MW	≥ 2.5 MW	≥ 3.0 MW
Vestas	DK	1997	1999	2010	2013
Goldwind	CN	2007	NA	2009	-
Enercon	DE	1995	2002	2002	2002
Siemens	DE	NA	2004	2004	2012
Suzlon	IN	2006-2007	2007-2008	NA	-
GE Wind	US	1998	NA	2006	2013
Gamesa	ES	NA	2003	2013	2008
United Power	CN	2011	2011	2012	2012
MingYang	CN	2007	2010	2010	2010
Nordex	DE	2001	2002	1999	2013

Table 4: Years of introduction of wind turbines in the respective size categories (own data)

This increased competition coincided with a decrease in turbine prices. From 2006[3] until their peak in 2010, the costs of WTGs increased steadily (with a small decline in 2009), while they decreased continuously in the following years. Although certain interrelations with commodity prices exist, they do not reflect all trends in turbine costs. This becomes clear, when looking at their price developments. While steel prices did rise steadily in 2006 and 2007 they increased around 70% during the first half of 2008. This is not reflected in turbine prices. In addition, steel and copper prices in 2011 reached a new peak (although not as high as in 2008) while turbine costs had already begun to decline.[4] Changes in the

[3] This year was chosen due to the availability of steel and copper prices as well as most reliable turbine costs

[4] Considering that effects on turbine costs by changing commodity prices might be delayed due to the lead times of the industry, we would expect these effects to become observable 2 years after the changes in commodity prices occur (similar to the time delay between the financial crisis and the stagnating global turbine installations in 2010). A first peak of steel prices in 2004/2005 would then explain the increased turbine costs in 2008, while the 2008 peak would be reflected in the 2010 turbine prices. Yet effects of the rising commodity prices throughout 2010 and 2011 cannot be observed in 2012 and 2013.

industry structure, as increased competition do, hence, also have effects on the recent cost decline (irena.org 2012).

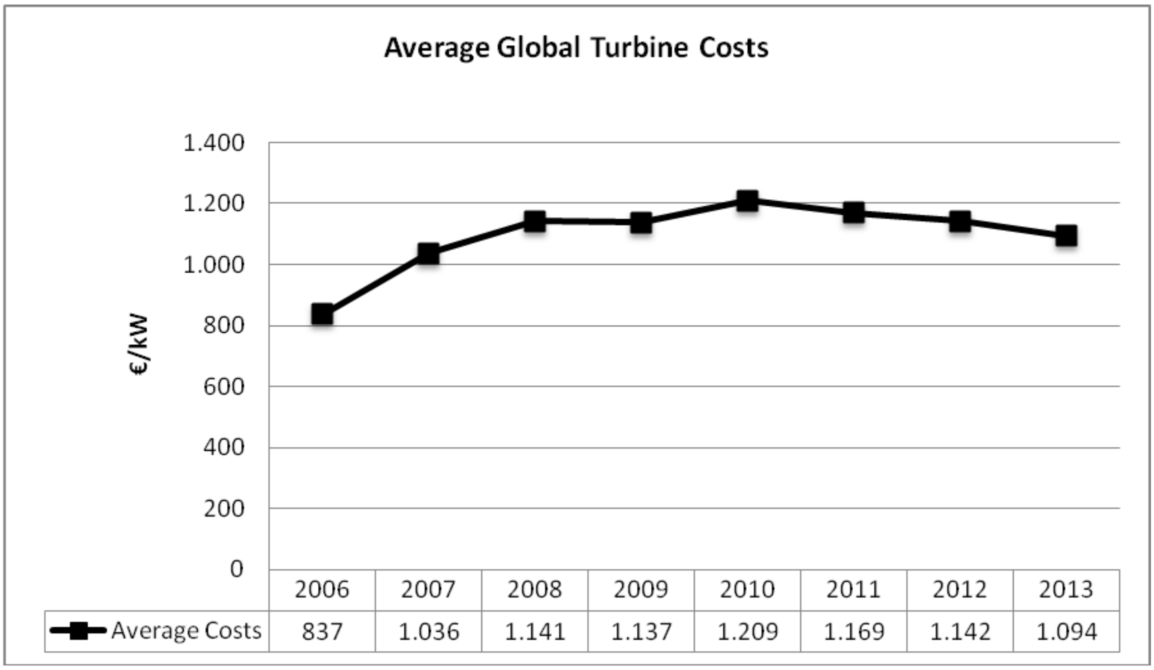

Figure 3: Average Costs of Wind Turbines per year (based on IRENA 2012 and IEA 2006 – 2013)

Development of International Standards

The development of global markets described above particularly took place from around 2006 on. It was at the same time that international standards have been increasingly implemented.

Standards are important elements in the modularization of production, as they provide generally accepted pieces of codified knowledge. In the wind energy sector, a certain degree of standardization and norm-setting set in almost 30 years ago. First standards were developed by national institutions such as the British Standards Institution or the Certification Committee for wind turbines in the Netherlands. Also Germanischer Lloyd in Germany started its activities as early as 1977. Other important organizations were certification companies such as Lloyds Register in the UK and DNV in Norway (Windpowermonthly 2012). As a result of globalizing markets certification also gained importance in countries like China, Japan, India or South Korea. However, guidelines were often only valid within national borders (Woebbeking 2008).

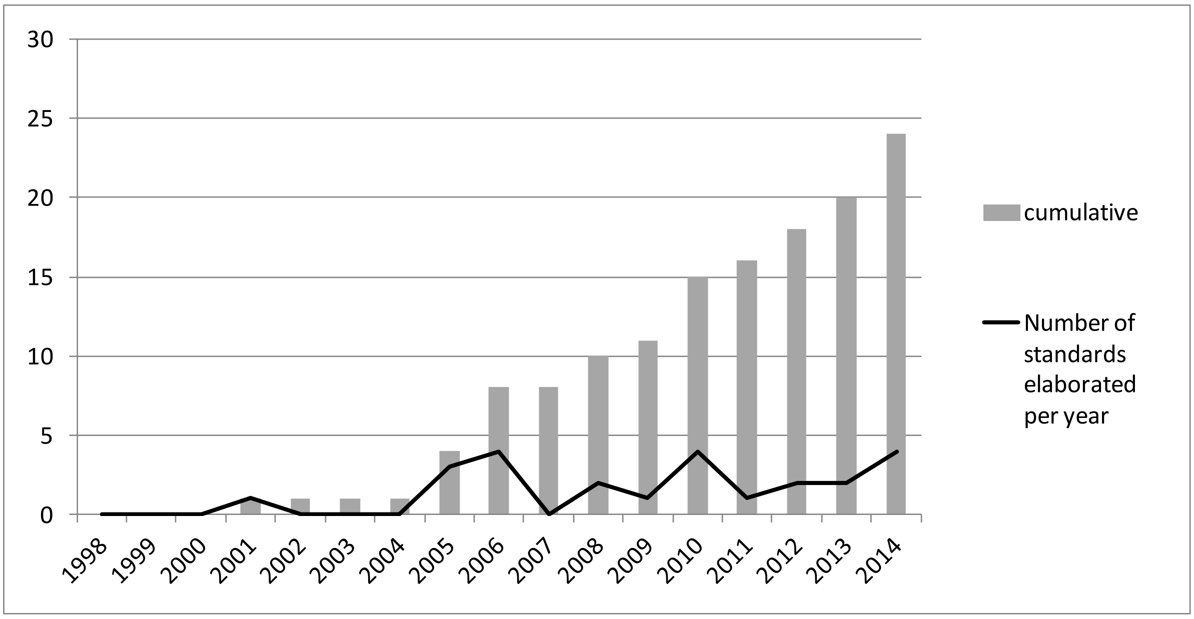

Figure 4: Publication of International Standards by the IEC (compiled by authors, based on data of Iec 2014)

First international efforts to develop global standards were taken in form of recommendations of the TC88 (Technical Committee 88) within the International Energy Agency (IEA) in the late 1980s. The development of internationally valid standards began in 1995. The first result, the IEC WT 01, was published in April 2001 by the organization's Conformity Assessment Board (CAB) (Windpowermonthly 2012). The IEC standards have been adopted by many countries, or have been used as basis for national standards (Hauschild 2006). Figure 4 illustrates that the publication of standards has intensified significantly particularly since 2005 (Iec 2012), i.e. a year before the structure of global top ten producers started to change.

To conclude, the industry experienced a structural change that started from 2006 on. It was not caused by a change in the dominant technological design. Instead, the established technological design became even more prevalent since 2007. In addition, the structural change took place in an industry took place that is in a growing and globalizing industry as well as increasingly covered by technical standards.

Different Modes of Production in the Global Wind Turbine Industry

The previous chapter illustrated the change in industry structure from an oligopolistic industry dominated by few firms to a more dispersed structure with less dominant firms. This change also coincides with a change in spatial origin of firms, from Danish, respective European, to geographically more dispersed firms as well as with a change of firm age, as younger producers appeared among the global top producers. It was furthermore shown, that the industry is becoming ever more global. This section goes to the level of the relation and describes the dominant mode of production in 2006 as well as the emergence of new modular forms of production.

Industry Structure and Dominant form of Production before the Disruption

A first wind energy industry in Europe formed in Denmark. The industry emerged geographically dispersed in small towns in rural areas often far away from agglomerations. For example, Vestas had its headquarters in Lem and Bonus, which later became Siemens Wind Energy, had its headquarters in Brande. The same pattern is found in other European countries. German Enercon is located in Aurich and Jacobs Windenergie (which later evolved into Repower, now Senvion) was formed in Husum.

Geographically distant from agglomerations, early producers had to convince other firms to provide supplies for turbine manufacturing (Karnøe and Garud 2012). In this environment, long-term and dense inter-firm relations emerged and suppliers often produces only for one manufacturer (Garud and Karnøe 2003). Within long-term relations, implicit knowledge of the mutual products and production processes was built up over years allowed for an efficient knowledge exchange. Accordingly, knowledge flows were bound to particular relations and not to a particular place and allowed for the flow of tacit knowledge despite geographically dispersion (Torre and Rallet 2005).

Garud and Karnøe (2003) describe how these inter-firm relations in the Danish wind energy industry led to the global dominance of Danish WTG-manufacturers. Due to the continual interactions within relations between customers, producers, suppliers, engineers and workers, knowledge about problems and performance of wind turbines as well as solutions for problems diffused fast. This knowledge exchange within "communities of practice" (Brown and Duguid 2001) led to increased reliability of Danish wind turbines.

This way to organize production and knowledge flows within long term relations emanates to other European producers. Lema et al. (2013) show that not only Danish, but generally European WTG-manufacturers often rely on exclusive supplier relations, i.e. they have only one supplier for a particular component and this supplier provides this component only for one WTG-manufacturer. They therefore speak of relational value chain organization in the European wind turbine industry.

Table 5 describes the degree of vertical integration of global top ten manufacturers in 2006 by showing the respective in-house production of core components. Additionally, it shows the market shares of the different WTG-manufacturers. Seven of the global top ten manufacturers in 2006 stem from Europe: two from Denmark, three from Germany and two from Spain. The remaining three were GE Energy from the US, Suzlon from India and Goldwind from China. European producers had a market share of 75,9% in 2006. Additionally, vertically integrated manufacturers, defined as those that produce at least three of the named components partly or completely in-house[5], accounted for 66,9% of global market share. Three of them, Gamesa, Vestas, and Enercon, with a combined market share of 59%, come from Europe, while Suzlon is the only non-European vertically highly integrated firm. [6]

These numbers indicate that indeed the industry was shaped by a European production model, of which vertical integration is an important element. Yet, the table also shows that it was not a monolithic model that accounts for all European firms. Especially smaller manufacturers like Acciona, Siemens and Nordex were vertically disintegrated. Table 3 also

[5] Two, when direct drive technology

[6] Table 5 also indicates if firms, in addition to vertical disintegration also dedicatedly applied platform strategies, i.e. a modularization on the product level. At that time, only the German manufacturer Repower (now Senvion) introduces a platform concept. Repower introduced such a strategy in 2001. Firms like Gamesa, Goldwind, Enercon, GE Wind Energy and Acciona also apply platform strategies, but we could not assign a year of the respective introduction. Firms like Vestas, Siemens, Suzlon or Nordex started to implement such strategies from 2010 on.

indicates if firms dedicatedly applied a platform strategy, i.e. a modularization on the product level. At that time, only the German manufacturer Repower followed such a strategy[7]

In 2006, there were existed also other modes of production. Garud and Karnøe (2003) described the early US wind turbine industry as following a more market based approach, whereby exchange between costumers, producers and suppliers, mostly took place via arms-length and market based forms of coordination. Dedrick and Kraemer (2011) showed with the example of the US wind turbine manufacturer Clipper that this firm is far less vertically integrated than its European counterparts. Also GE Energy is less vertically integrated than all other firms. Sturgeon (2003) argues that relational value chains are more prominent in Europe, while US firms would prefer more market based and therefore modular value chains, which certainly also accounts for GE Wind Energy. Another vertically less integrated producer is Chinese manufacturer Goldwind. According to Lema et al. (2013), Chinese producers follow modular ways of production organization. To conclude, there have been a variety of organizational forms of wind turbine production in 2006. However, the dominant model was a European one based on vertical integration and long term supplier relations, especially marked by firms like Vestas, Enercon and Gamesa.

[7] Repower introduced such a strategy in 2001. Firms like Gamesa, Goldwind, Enercon, GE Wind Energy and Acciona also apply platform strategies, but we could not find out if this was the case in 2006. Firms like Vestas, Siemens, Suzlon or Nordex started to implement such strategies from 2010 on.

	Vestas (DK)	Gamesa (ES)	Enercon (DE)	Siemens (DK)	Nordex (DE)	Repower (DE)	Acciona (ES)	GE (US)	Suzlon (IN)	Goldwind (CN)
Rotor	/	/	x	x	/	/	/	-	/	/
Gearbox	-	/		-	-	-		-	x	
Generator	x	/	x	-	-	-			/	x
Tower	/	/	x	-	-	-		-	/	
Plat. Strat						x				
Founded	1975	1994	1984	1980	1985	1991	1989	1996	1995	1998
Share	28,2%	15,6%	15,4%	7,3%	3,4%	3,2%	2,8%	15,5%	7,7%	2,8%

Supply by companies within the same parent company is classified as external.

x in-house manufacturing
- external supply
/ partly in-house and partly external supply
gearless technology

Table 5: Production Models and Industry Structure in 2006[8]

Emergence of a Modular Production Model

Since 2006, the industry is shaped by an intense increase of entry by Asian companies, especially from China (Kammer 2011). In these countries and especially in China, independent Industry emerged due to an increasing domestic demand for renewable energy combined with market entry barriers like local content requirements and financial support. The industry emerged, without any prior production experience in wind turbine manufacturing. In 2006, with Goldwind, the first Chinese producer appeared among the global top ten producers followed by manufacturers like Sinovel, Dongfang, United Power and Mingyang.

The strong growth combined with missing experience in WTG manufacturing led to an organizational model that differed from that of European firms. In the early 2000s, knowledge about WTG manufacturing was nearly completely missing. As part of the firm

[8] Where an external supply is known, but in-house production cannot be ruled out, the corresponding component has been classified as externally. For the opposite case the procedure was reversed accordingly. Incomplete information particularly refers to US and Chinese manufacturers, since difficulties in data collection (corporate communication policies and language barriers) showed

formation process, knowledge about the production of turbines was therefore purchased mainly in form of licenses from European manufacturers or design firms (Lema et al. 2013). These firms usually granted a license for the same -design to several Chinese manufacturers. While European firms each developed their own designs, these licensing processes entailed that several Chinese firms produced the same or at least very similar designs.

Figure 4 shows the development of licensing till 2009[9]. The graph shows a steep increase since 2005. Of the 52 licenses covered in this Figure, 46 licenses came from European manufacturers or design agencies. 29 licenses went to Chinese producers and additional 10 licenses to other Asian producers. These numbers show a considerable transfer of codified knowledge from European to Chinese manufacturers which is connected to the growth of a domestic industry in China.

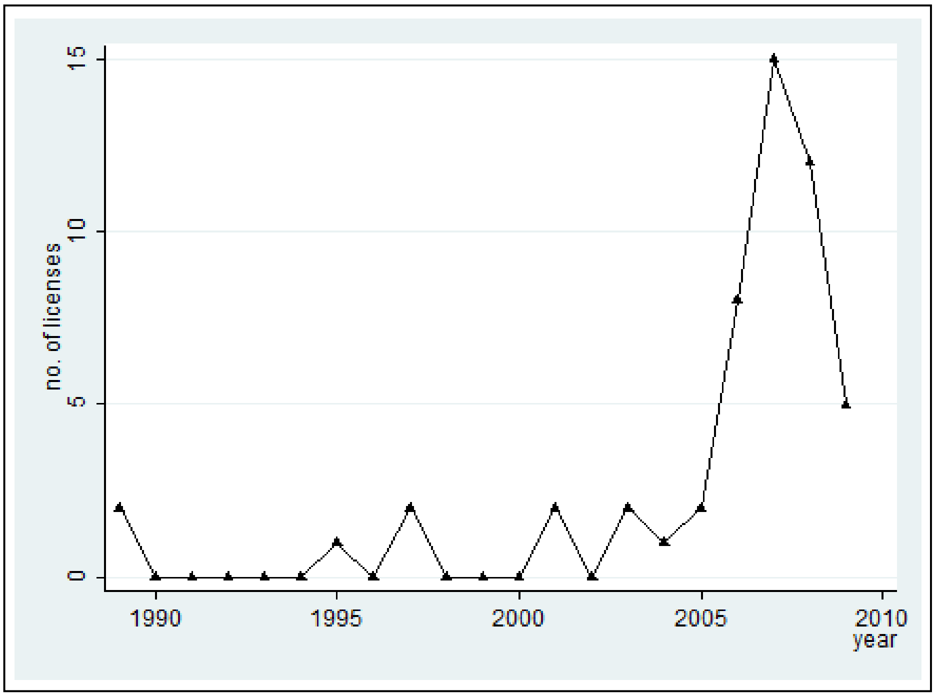

Figure 5: Number of Licenses of Wind Turbine Designs (own illustration, data from Kammer 2011)

[9] As the research stopped in 2009, especially licenses in this year might be unnoticed, leading to a decline.

As in the case of manufacturers, there was also no domestic supplier base in China. Components such as bearings, blades or controls had thus to be imported. Yet, the reliance on already established designs allowed the sourcing of components from a global market. As a result, Chinese manufacturers usually started as vertically more disintegrated firms with few components produced in-house (Lema et al. 2013).

Local content requirements between 2005 and 2010 of up to 70% of the value generation induced the emergence of a domestic supplier base. Due to the shared technological designs, the emerging supplier base did not have to develop specific components (gearboxes, generators or also rotor blades) for each single WTG-manufacturer. Instead, suppliers were able to deliver their components to several OEMs, while these in turn were able to choose between several suppliers for the same components.

With few exceptions, the typical Chinese turbine manufacturer only produces few components in-house. Therefore, the new firms applied a model production that was caused by processes of codification due to the in-licensing, combined with non-exclusive relations to suppliers, which provided components for different manufacturers. The typical model of production organization of Chinese firms can thus be termed as modular (Lema et al. 2013).

Relational Discontinuity in the Global Wind Turbine Industry

The typical model of highly vertically integrated firms and long term supplier relations of European firms and the model of modular production of Chinese firms both had their roots in the particular context in which the respective industries emerged. This section describes the production models in 2013 and especially the changes global manufacturers underwent since 2006

Strategies towards Modularization

Table 6 describes the vertical integration of the global top ten producers in 2013, supplemented by the manufacturers on the places 11 to 15. On the first glance, the top ten manufacturers do not differ much from 2006. Actually, the number of vertically integrated manufacturers increased. In addition to Vestas, Enercon, Gamesa and Suzlon which appeared also in the 2006 table, the vertically integrated Chinese manufacturer United Power, appeared on the list. Yet, there are several differences. The first is the number of manufacturers that dedicatedly applied platform strategies and in doing so introduced modularity on the product level. With the exception of Mingyang where we do not have information, all top ten producers introduced platform strategies and modular product designs. We know the respective date from several firms. Most of them introduced platform strategies only recently: Vestas started in 2012, Siemens in 2012, Suzlon in about 2010, Nordex in 2010. Only REpower already applied such strategies already in 2001.

In addition to modularization on the product level, several manufacturers outsourced the production or parts of their production of components and broadened their supplier base. For the following manufacturers, we have a date for their broadening of supplier base or sale of in-house production. Vestas announced in 2009 to broaden its supplier base and sold a tower factory in 2012. It has furthermore reduced the number of manufacturing plants from 31 in 2012 to 19 sites today. Gamesa also announced broadening its supplier base in 2011 and for example dropped its share of in-house production between 2010 and 2013 for blades from 72% to 50%, for gearboxes from 65% to 47% and for generators from 88% to 69%. Nordex announced to broaden its supplier base in 2012. Suzlon sold with Hansen its complete gearbox production to ZF Friedrichshafen in 2011. Goldwind bought blade manufacturer Xiexin in 2010, but also sold blade manufacturer Tellhow in 2012.

This enumeration shows that in addition to the product design also strategies to modularize supplier relations were mostly applied by vertically integrated firms like Vestas, Gamesa or Suzlon. Additionally, these firms also connected product modularization and modularization of supplier relations in the form of broadening of supplier base and outsourcing. Only Enercon just applied modularization on the product level without a change of supplier relations. Finally, most of the strategies to modularize supplier relations started around 2009 and 2010. The only exception is Repower, which intended to broaden its supplier base already in 2006, but also was an outlier with the implementation of a platform strategy in 2001.

The industry pattern of 2013 showed that the industry considerably changed since 2006. Since then, nearly all firms adopted modularization strategies on the level of the product and on the level of their supplier relations.

Top 10 Manufacturer											Top 11-15 Manufacturer				
	Vestas (DK)	Goldwind CN)	Enercon (DE)	Siemens (DK)	Suzlon (IN)	GE (US)	Gamesa (ES)	United Power (CN)	Mingyang (CN)	Nordex (DE)	XEMC (CN)	Envision (CN)	DEC (CN)	Sinovel (CN)	Sewind (CN)
Rotor	/	-	x	x	/	-	/	x	x	/	x	-	/	-	-
Gearbox	-			-	-	-	/	x	-	-		-	-	-	-
Generator	x	x	x	-	/		/	x	-	-	x	-	/	-	x
Tower	/	-	x	-	/	-	/	-	-	-	-	-	/	-	-
Platform Strategy	x	x	x	x	x	x	x	x	x	x	x	?	?	x	x
Established	1975	1998	1984	1980	1995	1996	1994	2006	2007	1985	2007	2007	2004	2006	2006
Share	13,2%	10,3%	10,1%	8,0%	6,3%	4,9%	4,6%	3,9%	3,7%	3,4%	3,2%	3,1%	2,3%	2,3%	2,2%

Supply by companies within the same parent company is classified as external.

x in-house manufacturing
- external supply
/ partly in-house, partly external supply
(grey box) gearless technology

Table 6: Production Models and Industry Structure in 2013

In addition to the strategies of modularization applied by most top ten producers, a second important difference between 2013 and 2006 is the market share of different global top ten manufacturers. On the one hand, the relation between the shares of European, American and Chinese manufacturers changed clearly from around 75%, 15% and 10% respectively to 40%, 5% and 25% in 2013. On the other hand the market shares of vertical integrated manufacturers and those producing in a modular way changed significantly.

Compared to 2006, the cumulative market share of vertically integrated producers declined from 66,9% to 38,1%. This decline includes United Power and thus one more manufacturer than in 2006. Additionally, Repower (now Senvion), which appeared as vertically disintegrated manufacturer in the 2006 is now listed as part of the vertically integrated manufacturer Suzlon. In contrast to the vertically integrated manufacturers, the share of modular producing firms among top ten producers only slightly decreased from 35% to 30,3%. These trends can also be observed when applying other values for the indicator 'external sourcing of components'.

The share of European producers declined from 75,9% (2006) to 39,3% (2013). This decline especially seems to affect vertically integrated European producers like Vestas, Gamesa and Enercon, whose market share more than halved from 59,2% to 27,9%. Although European manufacturers that produced in a more modular way like Siemens and Nordex also had a declining market share, it was less pronounced (16,7% to 11,4%) and resembles the general decline of market share of global top ten manufacturers.

For the Chinese turbine manufacturers the picture looks quite similar. While the modular producing companies increased their share from 2,8% in 2006 to 14% in 2013, the relational manufacturers only increased their share from 0% in 2006 to around 4% in 2013.

Figure 6 shows the relative shares of the traditionally modular and relational European and Chinese manufacturers to each other (GE Energy and Suzlon are thus not included). All manufacturers are categorized according to their form of value chain organization in 2006 to show how companies with different traditional forms of value chain governance where affected differently over time.

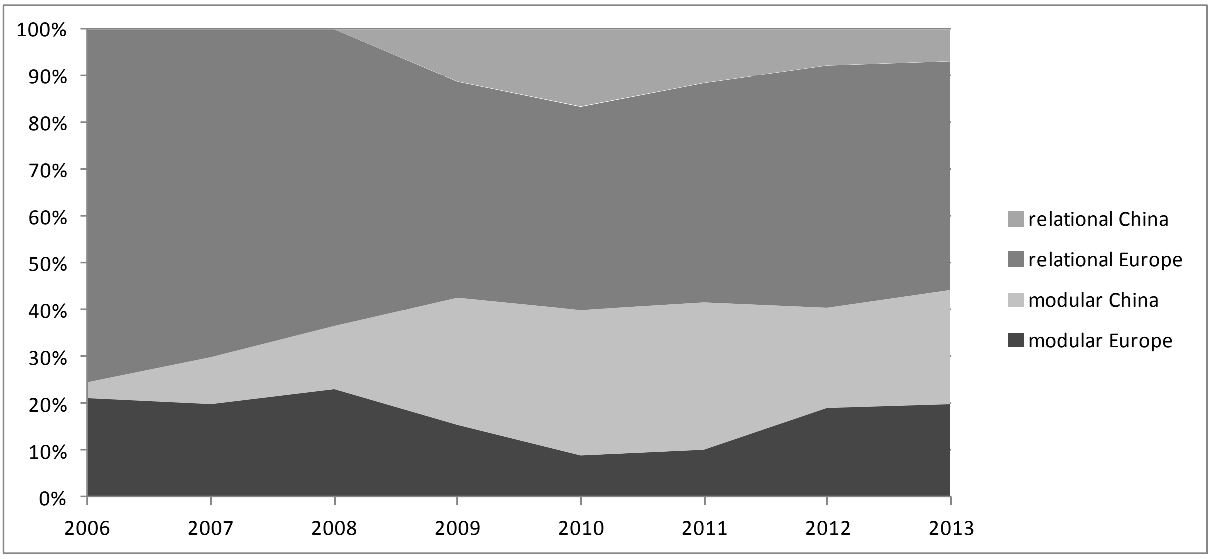

Figure 6: Relative Shares of WTG-manufacturers in the global wind turbine market

It becomes clear that it is not only the emergence and establishment of Chinese manufacturers among the global top ten that is changing the industry. As the vertically more integrated companies in Europe loose bigger shares than the more modular ones and in the same time the modular Chinese companies gain more market shares then their relational counterparts, the industry is undergoing a process of a growing new form of value chain governance while traditional relational form of value chain governance is confronted with an continuous decline of its previous dominance.

It thus seems that the industry is currently facing a transition. Especially the qualities of the WTG-manufactures on rank 11 to 15 point in this direction. All of them are Chinese manufacturers and none of them is older than 10 years. Yet even including them, would increase the share of modular manufacturers to only 37,9%, while also increasing the relational share to 43,6%. Therefore, the previous dominant model was not replaced by a new dominant modular model yet.

The numbers indicate the end of a dominant European model of production consisting of high degrees of vertical integration and long-term and exclusive supplier relations. Especially those firms lost most market shares that were most strongly attached to the old production model. However, these numbers do not indicate that there already is a new dominant mode of modular production as the shares of modular manufacturers are still smaller.

Conclusion

We started with the observation that the structure of the global wind turbine industry exhibited some profound changes since 2006. The market share of the top ten producers on total global production suddenly declined and the old oligopolistic structure of the industry seems to vanish. Additionally, we observed changes that resemble those accruing from a technological discontinuity (Anderson and Tushman 1990). We found new market entries and new market leaders and a demise of old market leaders. Yet, there was no significant technological change that could have caused this discontinuity.

Most of these new entries and market leaders come from China. Therefore, the changes of the industry structure could be explained by the emergence of a domestic industry in China. However, the structural changes appear to be more profound. New entrants from China seemed to adopt a production model shaped by modularity that differed from those of established firms (Lema et al. 2013).

Therefore, we followed the thesis that the industry indeed faces a discontinuity. However, the discontinuity is not shaped by the introduction of a new product or process technology. Instead, we argued that the discontinuity is caused by new and modular forms to organize productions which are introduced by Chinese firms on a broad level. As modular production changes the relations between product components as well as between suppliers and manufacturers, we term it a “relational discontinuity”.

A discontinuity takes place in industries with a dominant design. Accordingly, we expected the industry to have a dominant form of production organization that changes towards modular forms of production. Additionally, we expected especially those firms to suffer from this change that were deeply embedded into the previously dominant form of production.

We analyzed modularization on the level of the product and the supplier relation. We used market shares of global top ten producers to account for changes on the structural level as well as for the performance of different firms. We used degrees of vertical integration as well as qualitative accounts as measure for the organizational mode of a manufacturer (Sturgeon 2002). We analyzed business reports regarding the introduction of modular product design or platform strategies and change of supplier relations. To analyze the discontinuity, we compared the development of the industry between 2006, which is the last year before the industry structure changed, and 2013 which is the last observable year.

We showed that there indeed was a dominant model of production in 2006. Back then, the industry was shaped by mostly European highly vertically integrated firms with exclusive and long term supplier relations. This model came close to what Gereffi et al. (2005) term “relational value chains”. Other forms of production existed in different national markets like in the US with GE Energy and in China with first Chinese manufacturers.

We found indications that modularity indeed disrupted this dominant model of production. First, while not necessarily producing in a perfectly modular way, all large global manufacturers implemented different forms of modularization on the levels of the product and their supplier relations in 2013. Second, established firms introduced modular forms within quite a short time period, mostly between 2009 and 2012. Thus, after firms that already applied such forms, mostly from China, entered the industry in larger numbers. Third, those firms that were the most typical examples of the previous dominant production model suffered most from the relational discontinuity. Fourth, on the industry level, the previous dominant mode of production is being more and more replaced by a new modular form of production. Fifth, these developments took place in a time when firms and their respective production models increasingly started to compete on the same markets.

However, the previous dominant model was not replaced by a new dominant model based on modular production. Established firms applied modularization strategies especially on the product level, but Suzlon, Vestas and Goldwind also vertically disintegrated by selling its gearbox, tower and blade manufacturer respectively. Additionally, vertically integrated firms still account for the largest market shares.

The industry seems to be in a phase of transition and the transition is caused by the pervasive introduction of modular forms of production organization. Yet, as Tushman and Anderson (1986) state, the technology that defines the discontinuity usually does not become the later dominant design. Different forms might evolve during this "era of ferment" (Anderson and Tushman 1990). Examples are a combination of vertical integration on levels like the blades and modular production organization on levels like generators, gearboxes, and towers (e.g. Siemens and Mingyang). Also, some components might still be produced in-house, while the predominant part is sourced by several external suppliers, representing modular value chain aspects. Yet, dominant product architecture and the increasing globalizing industry indicate that there is a certain propensity that there will be a new dominant form of production organization. As firms increasingly produce for different markets, which sometimes are restricted by local content requirements, and benefit by developing routines to deal with changing suppliers, modularization will play a role in these future developments.

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