

Paper to be presented at the DRUID Academy 2012

on

January 19-21 at University of Cambridge /The Moeller Centre

Technology and market dynamics in the wind energy sector: do first

mover advantages exist? An exploratory analysis on the level of (national)

innovation systems.

roberta squillace SCUOLA SUPERIORE SANT ANNA management roberta.squillace@gmail.com

Abstract

Technology and market dynamics in the wind energy sector: do first mover advantages exist? An exploratory analysis on the level of (national) innovation systems.

Roberta Squillace Scuola Superiore Sant?Anna Year of Enrolment: 2009 Expected Final date: October 2012 Paper in collaboration with Prof. B. Van Looy, K.U.Leuven r.squillace@sssup.it roberta.squillace@gmail.com

Wind energy is currently experiencing considerable growth: the capacity installed displays an annual two-digit growth rate in the last ten years. At the same time it can be noted that this growth has been preceded by a long period of ?stagnation?, characterized by moderate levels of technological and economic activities. While the observation that life cycle dynamics are present within this industry (see Abernathy & Utterback, 1992; Andersen, 2006) might come as no surprise, this industry and its underlying technologies offers the opportunity to address a number of questions on the level of innovation and technology dynamics: to what extent does one observe ?first mover? advantages ? on the level of (national) innovation systems (see Ludnvall, 1992; Nelson, 1993) - within this industry (and its constituting technologies)? To the extent that such first mover advantage are present, which distinctive characteristics of (national) innovation systems (e.g. contributions of scientific actors, the presence of supportive policies, including local demand)

contribute to these dynamics?

In order to address these questions, a panel dataset has been created including data on Installed capacity, R&D Expenditures and Government Policies which include investment incentives, taxes, tariffs, obligations and permits. To assess technological performance, we relied on patent data extracted from the Patstat Database (Version October 2010) referring to the entire wind supply chain, according to the new classification scheme for renewable energy technologies (EPO, 2010). The panel data set spans a time period of 30 years (1978 ? 2008) and includes 24 countries. Combined, these countries account for 95% of the overall patent activity (EPO) and of installed wind capacity worldwide.

A first part of the analysis relates to the delineation of different phases within the development of the technology. Our findings reveal an S-shaped development pattern, with an ?incubation? phase ranging from 1978 to 1993; followed by rapid growth from 1994 onwards.

Next, we analysed whether (national) innovation systems that ?lead? the developments in the first phase are also dominant (in terms of technology and market share) during the second, growth, phase. Overall, our findings confirm the presence/occurrence of both path dependency and creation dynamics (Garud & Karnoe, 2003): while a considerable number of countries are explicitly present within both time periods, newcomers can and do play a role during the second, growth, phase. Finally we analyse whether and to what extent antecedents of performance are similar/different between both phases by means of panel data models. Econometric field clearly signal that the relevance and impact of antecedents vary considerably over time: R&D expenditures and technology activity undertaken at universities and research centres are relevant in the incubation phase, while the development of the wind capacity installed and government policies are more influential during the growth phase.

Policy implications, limitations and directions for further research will be addressed.

Technology and market dynamics in the wind energy sector: do first mover

advantages exist? An exploratory analysis on the level of (national) innovation

systems.

Scuola Superiore Sant'Anna Year of Enrolment: 2009 Expected Final date: October 2012 Paper in collaboration with Prof. B. Van Looy, K.U.Leuven r.squillace@sssup.it roberta.squillace@gmail.com

Abstract

Wind energy is currently experiencing considerable growth: the capacity installed displays an annual two-digit growth rate in the last ten years. At the same time it can be noted that this growth has been preceded by a long period of 'stagnation', characterized by moderate levels of technological and economic activities. While the observation that life cycle dynamics are present within this industry (see Abernathy & Utterback, 1992; Andersen, 2006) might come as no surprise, this industry and its underlying technologies offers the opportunity to address a number of questions on the level of innovation and technology dynamics: to what extent does one observe 'first mover' advantages – on the level of (national) innovation systems (see Ludnvall, 1992; Nelson, 1993) - within this industry (and its constituting technologies)? To the extent that such first mover advantage are present, which distinctive characteristics of (national) innovation systems (e.g. contributions of scientific actors, the presence of supportive policies, including local demand) contribute to these dynamics?

In order to address these questions, a panel dataset has been created including data on Installed capacity, R&D Expenditures and Government Policies, which include investment incentives, taxes, tariffs, obligations and permits. To assess technological performance, we relied on patent data extracted from the Patstat Database (Version October 2010) referring to the entire wind supply chain, according to the new classification scheme for renewable energy technologies (EPO, 2010). The panel data set spans a time period of 30 years (1978 – 2008) and includes 24 countries. Combined, these countries account for 95% of the overall patent activity (EPO) and of installed wind capacity worldwide.

A first part of the analysis relates to the delineation of different phases within the development of the technology. Our findings reveal an S-shaped development pattern, with an 'incubation' phase ranging from 1978 to 1993; followed by rapid growth from 1994 onwards.

Next, we analysed whether (national) innovation systems that 'lead' the

developments in the first phase are also dominant (in terms of technology and market share) during the second, growth, phase. Overall, our findings confirm the presence/occurrence of both path dependency and creation dynamics (Garud & Karnoe, 2003): while a considerable number of countries are explicitly present within both time periods, newcomers can and do play a role during the second, growth, phase. Finally we analyse whether and to what extent antecedents of performance are similar/different between both phases by means of panel data models. Econometric field clearly signal that the relevance and impact of antecedents vary considerably over time: R&D expenditures and technology activity undertaken at universities and research centres are relevant in the incubation phase, while the development of the wind capacity installed and government policies are more influential during the growth phase.

Policy implications, limitations and directions for further research will be addressed.

JEL CODE 033, Q42

1. Introduction

In recent years, there has been a huge increase of investments on renewable energies sources worldwide, in order to arrive at a 'low carbon' energy sector. Wind energy, in particular, has been one of the more dynamic fields with a capacity installed that has grown in the last ten years at two-digit rate worldwide. The recent widespread of wind technology could not have happened without relevant progress in the underlying technology during the last three decades, resulting in more efficient wind turbines. In fact, while the principles and practices required to generate electricity from harnessing wind, was known since the end of the 19° century the development of the modern wind power industry begun since the middle of the 70s. The modern wind industry has been the result of three decades of failures and successes: for years the industry was small and prototypes were created by the support of government funds. Major problems hampering the growth of the industry relate to efficiency/cost-effectiveness, noise levels and technology stability. Research and development efforts laid the basis for the modern wind industry that had a huge improvement in term of technology performance, mainly for two reasons. First, technology progress has shown that wind energy could be applied at large scale and be integrated in the electricity system, and not only to satisfy the energy demand of remote areas. The main consequence is a new approach to the electricity system: distributed generation solutions that could work with the traditional centralised facilities to satisfy energy demand. Second, wind energy has entered into the national

energy plans of many industrialised countries, alongside traditional fossil fuels and nuclear energy.

Recently some studies have been carried out, concentrating mostly on the dynamics of technology diffusion (Popp et al., 2011) or the role and impact of supportive policies (Lewis and Wiser, 2006; Johnstone et al., 2010; Dechezleprêtre and Glachant, 2011). A number of studies have investigated the dynamics of the wind technology industry. Garud and Karnøe (2003) compared and explained industry dynamics in Denmark and US and advance the notions of "bricolage versus breakthrough" while, more recently, Hendry and Harborne (2011) found "more than bricolage" in the recent modern development of the wind industry in Denmark.

This paper wants to complement these efforts by examining the evolution of wind technology over time and to assess the presence of (national) innovation system characteristics and their impact on the technological performance of (national) innovation systems.

Analyzing the development of the wind technology trajectory over the last thirty years, measured by patenting activity, reveals a typical s-shape curve, where the current growth has been preceded by a long period of 'incubation', characterized by moderate levels of technological and economic activities. Life cycle dynamics have been further investigated on the level of national innovation systems (countries). More specifically, we examined whether and to what extent one observes 'first mover' advantages. Our findings do reveal the occurrence of first mover advantages at the level of innovation systems: a number of countries that are 'leading' during the incubation phase, retain a dominant position during the consecutive growth period.

At the same time, we also observe new entrants, able to gain a considerable share of the technology market, despite moderate activities during the first phase.

Within a next step, we analysed the impact of characteristics of national innovation systems (notably the contributions of scientific actors, the presence of supportive policies, including local demand) on the technological performance of (national) innovation systems. The outcomes of the econometric panel models, carried out for both periods of the technology path (incubation and growth) reveal that antecedents of technological performance vary between both periods. While R&D oriented policies have a considerable impact during the incubation period, this is not the case during the growth phase, where the development of the domestic market and market supportive government policies play a more important role.

The paper is structured in the following manner: in the next section, a discussion on the technology dynamics in the wind sector is provided and complemented with insights offered by the literature on innovation and technology dynamics resulting in the main research questions being addressed. Paragraph 3 and 4, respectively, discuss the data, methods and results obtained. Finally, conclusions, limitations, and directions for further research are elaborated in the final section that concludes this study. An appendix with the description of the main statistical results obtained is included.

2. Technology dynamics in the wind sector and Research Questions

Technological innovation is commonly recognised as a key factor in explaining economic development and industry performance. Kondriatiev (1925) found that capitalist economies go from boom to bust in a long cycle or "wave" and that there is a link between long waves of economic development and the rise and fall of technologies. Schumpeter (1939) expanded Kondriatiev's work, characterising innovation as "industrial mutation," which "incessantly revolutionises the economic structure from within", by a process of "creative destruction"; innovations occur at "irregularly regular" intervals rather than gradual; therefore, innovations and the diffusion of radical technologies result in long economic cycles, which follow the evolutionary path of successive technology replacements. The debate on innovation dynamism was further developed during the 1950s, 1960s and 1970s, when a series of "linear models" appeared advancing different 'drivers' of technological progress, the so-called "science and technology-push" (Bush, 1945) and "market-pull" (Mowery and Rosenberg, 1979; Griliches, 1957; Schmookler, 1966; Vernon, 1966). While linear models of innovation became popular in academic research, they were not without criticism and new models have been introduced, such as the chain-linked model (Kline, 1985), based on the concept of feedback loops in the innovation process and the "interaction model" which emphasizes an on-going activity and interaction of different institutional sectors (research institutions, enterprises) and the market (Schmoch et al., 1996).

Theories on innovation dynamics influenced theories on the analysis of cyclical

forms of technology activity. The most common indicator of technology activity, used to assess the relationship between inventions and investments longitudinally, is the patent activity index (Schmookler, 1962)¹. According to classical 'linear' models of innovation, the patent activity index within an industry generally follows a sigmoid curve, commonly named as S-shape curve. The development of new more complex theories of innovation have led to more accurate analyses of long-term patent activity in some sectors as well, revealing more complex patterns than simple S-shape curve, for instance, double-S-shape (Haupt et al., 2007) that can be explained in terms of "double boom" cycles (Schmoch, 2007). Typically, life cycle dynamics within industries imply a considerable incubation phase where relevant technological problems need to be resolved, therefore, the number of patent applications is low and increases slowly; coping with the basic technological problems, high costs of developing the new product and unclear market applications. Within this phase, the development of patent applications can even stagnate or decline; only when the most relevant uncertainties are resolved, the number of patent applications increases again rapidly and the growth stage begins (Utterback and Abernathy, 1975).

This complex path of technology, measured by the patent activity index, is found in the empirical field of wind energy technology as well. More than 14,000 patents were extracted by using the PATSTAT database (2010 version) for the EPO, USPTO and WIPO systems, having a priority date between 1978 and 2008. Patents include both applicants and grants. Patent counts are generated for each of the IPC classification and Ecla.Epo classification (EPO 2010), relating to the wind sector, that include not only the wind turbine technology, which previous studies have focus on (Johnstone, 2009; WIPO, 2007), but also the other main components like blades, nacelle, gearboxes, generators and control system that belong to the supply chain. Then data have been subjected at the "name harmonization" procedure in order to correctly allocates name variants to a single, harmonized name.

Patent data search	h criteria
ipc class	'B60K 16/%'; 'B60L 8/%'; 'B63B 35/%'; 'B63H 13/%'; 'E04H 12/%';
	'F03D%'; 'H02K 7/18%'.
ecla.epo_class	'Y02E10:70%'; 'Y02E10:71%'; 'Y02E10:72%'; 'Y02E10:73%'; 'Y02E10:74%';
	'Y02E10:75%'; 'Y02E10:76A%'; 'Y02E10:76B%'; 'Y02E10:76C%';
	'Y02E10:76D%'.
Source: Inc class	sification EBO 2010

Source: Ipc classification, EPO 2010

The patent activity index, follows a typical S-shape curve.

Fig. 1. The wind patent activity path, approximated by an S-shape curve.



Source: Elaboration from data extracted in Patastat Database

As fig. 1 shows clearly, a long 'incubation' period is found, approximately until the year 1993, where patenting activity is marginal and uncertain and the share of patents filled by companies vary between a minimum of 34 to a maximum of 56% of the total patents applied. Then, a rapid increase of patenting activity occurs and,

simultaneously, the patenting activity carried out by company increases as well, passing quickly from an average value above 50% in the late 90s to values above 70% in the early 2000s up to maximum values around 84-88% in 2004-2008.

While the observation that life cycle dynamics are present within this industry might come as no surprise, this industry and its underlying technologies offers the opportunity to address a number of questions on the level of innovation and technology dynamics.

Given these life cycle dynamics/phases, one can question whether and to what extent early entrants – active already in the incubation period – are also dominant players during the consecutive growth phase. We analyse this question on the level of national innovation systems (countries) (Freeman, 1988; Lundvall, 1992; Nelson, 1993; Foxon et al, 2005), as conditions that support or hamper the development of a certain technologies vary greatly between countries. Moreover, which distinctive characteristics of national innovation systems (e.g. the participation of scientific actors, the presence of supportive policies, local demand) contribute to these dynamics that occur at country level? Are antecedents of performance similar or different during the incubation and growth phase of technology?

Therefore the research questions that will be addressed in the paper are the following:

RQ1: Do we observe first mover advantages – at the level of national innovation systems – in the wind technology sector?

RQ2: Which factors contribute to these dynamics? Are antecedents of performance similar/different during both phases?

3. First mover advantage of national systems of innovation: data, analysis and results

In order to address the first question, the wind patent activity index found as descripted in the previous paragraph is calculated per country. Patents are allocated to countries based on the nationality of the "inventor", instead of the criteria of the nationality of "applicant" used in previous studies (Popp et al., 2011; Johnstone et al., 2010). In the wind sector multinational firms are participating in the development of technologies and markets; for these companies, the applicant is often the parent company, although the technology has been created in subsidiaries. Moreover, the wind industry has been characterised by mergers and acquisitions. Then there is the risk that, using the "applicant" country criteria, patenting activity is not allocated properlyⁱⁱ. Therefore, the "inventor" criteria, although not perfect at all, fits better. Fig. 2 shows results for those 24 countries with the highest level of technology production; they together account for 93-98% of the overall patenting activity.

In terms of the total number of patents filled, countries leading in the incubation phase (1978-1993), are still leaders in the growth period, with a few exceptions like Denmark that has reached the 4th position, just after Japan Germany and US. It doesn't surprise really that Unites States, Germany and Japan are the most active countries, being the countries with a high level of GDP and with a very high propensity to patent activity, according to the OECD statistics; for this reason, the patent activity of countries is normalized for the size of their economy (e.g. number of patents respect GDP expressed in US\$ current price, current PPP). The scenario

changes significantly among the two time periods. The most impressive case is Denmark that become the technology leader, while countries as Norway and Germany overcome those countries like Sweden, Finland, United States and The Netherlands that have been 'leaders' in the previous period.

Fig.2. Top countries in the incubation and growth phases and the rank order correlations for both periods



		Correlations		
			Patents7893	Patents9408
endall's tau_b	Patents7893	Correlation Coefficienta	1.000	.715
		Sig. (2-tailed)		.000
		Ν	24	24
	Patents9408	Correlation Coefficient	.715	1.00

Sig. (2-tailed)

Ν

**. Correlation is significant at the 0.01 level (2-tailed).

Κ

.000 24 .000

24

.000

24



Correlations								
			PatperCap7893	PatperCap9408				
Kendall's tau_b	PatperCap7893	Correlation Coefficient	1.000	.686**				
		Sig. (2-tailed)		.000				
		Ν	24	24				
	PatperCap9408	Correlation Coefficient	.686	1.000				
		Sig. (2-tailed)	.000					
		Ν	24	24				

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Elaboration from data extracted in Patastat Database

Therefore, empirically, our results do suggest that countries that have participated in the development of the wind technology in the early phase can profit during the growth phase as well. At the same time, this relationship is not deterministic: path creation dynamics seem to be as present as path dependent ones.

The results on technology performance of countries are coherent with some insights arising from the history of the wind power industry that has seen United States, the Netherlands and Sweden starting investing in the development of the technology with ad hoc program since the end of the 70s and, later, be overcome by new countries able to make those technology changes necessary to take the lead. In US, for instance, the first program for large horizontal-axis wind turbines was initiated from 1974 to mid-80s, NASA's Glenn Research Center with the cooperation of companies as Boeing and General Electric, putting in operation four major wind turbine designs: 200 kw (MOD 0), 2 MW (MOD 1), 2.5 MW (MOD 2) and 3.2 MW (MOD 5) wind turbines. Although NASA research and prototypes pioneered many of the multi-megawatt turbine technologies and design in use todayⁱⁱⁱ, none of the NASA prototypes became commonly produced and, the technology activity gradually declined during the second half of 1980's and continued into the 1990s, when the wind industry that was born during the wind market boom between 1981 and 1987 (promoted by the Federal and State incentives) lagged and then declined as well. Later, since the end of the 90s, United States accelerated the technology activity, achieving again a dominant role (General Electric, the major US wind turbine company, is one of the top players worldwide) but some positions were lost in the technology international competition.

In Sweden, the wind power became an issue on the political agenda in 1975 when the Wind Energy Research Programme was launched, followed by the Energy Technology Fund in 1988. Between 1975 and 2000 about ten different companies were engaged in wind turbine manufacturing in Sweden. During the early 1990s three Swedish companies, Zephyr, Nordic Windpower and Kvaerner Turbin commissioned turbines for planned commercial production. Today the role of Sweden is still crucial in terms of technology development but it has changed: there are only two Swedish producers of large-scale wind turbines left in Sweden, Nordic Wind Power and SW Vindkraft, while the number of Swedish subcontractors and component suppliers has increased over recent years. Today there is a range of Swedish suppliers, from specialised component manufacturers to system suppliers, that manufacture components for both the Swedish and international market, like ABB (Astrand, 2011).

In The Netherlands, the Dutch wind turbine innovation system was set up after 1976. Before this time the Dutch had no experience of building wind turbines for electricity generation; Then, as a result of the 1975 LSEO interim report, wind energy became an important topic and the Dutch wind turbine innovation concentrated on playing the role of guiding the country in the field of wind energy, developing both large-scale and small-scale wind turbines. The efforts involved mainly large firms and energy research institutes and several smaller companies entered the market. However, since the mid of 80s, large changes in the so called "wind turbine innovation subsystem" occurred: "Fokker" for instance left the wind market, "Stork" stopped building wind turbines, but continued building blades and doing research and Holec, who had become a wind turbine manufacturer after taking over the company Van der Pol, disappeared in the early 1990s; smaller companies incurred financial problems that resulted in mergers and exits. The research institutes and universities, by contrast, were still very active. While the Netherlands were very active during the early stage, the Netherlands were not able to become internationally leaders during the growth phase and they have recently suffered from competition from other countries such as Germany and Denmark.

Germany started to support wind turbine development, after the oil crisis, with federal government R&D programs initiated in 1974. The government's large-scale

14

wind plant project (GROWIAN) developed the largest wind turbine ever before built, but the plant was dismantled in 1987 and was considered an economic failure, due to limitations in manufacturing and system integration. In Germany the wind market further developed in the late 80s and the 90s, promoted by the federal Electricity Feed Law (StrEG) adopted in 1989 as a "100 MW Wind Programme" (extended to the 250 MW Wind Programme in 1991). While the home market has grown, the technology activity of the country have increased as well, achieving a quite better rank in relative patenting activities during the growth phase. German companies which have become international market leaders, like Enercon (1989), Nordex (that located from Denmark to Germany in 1991) and Repower (2001).

The successful case of Denmark wind industry has been explained through a) processes of "bricolage" during the incubation phase, defined as resourceful improvisation in contrast to the R&D-led "breakthrough" model of innovation espoused by its high-tech competitors, the US, Dutch, British and Swedes (Garud and Karnøe, 2003); and later on b) "more than bricolage", that involved a reassertion of science-based R&D as a decisive factor for long-term Danish success (Hendry and Harborne, 2011). Examining the trend of the patenting activity in Denmark, it can be noted that during the incubation phase, Denmark is involved in the technology activity marginally. It can be explained by the fact that by the 80s, Vestas and other Danish wind turbine firms, instead of pursuing an intensive R&D, deployed prototypes designed with simple engineering heuristics to engender a process of trial-and-error learning, supported on the one hand by the experience in the domestic market and also by the results in technology achieved by the engineers at the Danish

Wind Turbine Test Station (DWTS). However, since the late 80s, learning from the California experience^{iv}, the Danish companies kept their technological competencies in place and further developed the technology and scaled-up new generation turbines. The technology experience accumulated in the early years and the new consciousness of the need of improving wind technology for becoming market leaders, has led Denmark to achieve excellent technology performance.

Denmark not only attracted R&D activities of Danish and foreign top manufacturers companies but it has also promoted the development of new knowledge and technology competences abroad. An interesting case is Norway. That has a marginal domestic wind market, but has created a wind industry specialised in subcontracting for the Danish wind turbine industry. Kristiansand Jernstøperi (KJ) is the R&D centre of the WindCast Group, bought by Vestas in 2002/3. KJ had about 50% of the world market for castings in 2003. Devold AMT (about 50% of the world market for glass fiber materials for wind turbine blades in 2003), Dokka Industrier (bolts), Jotun Polymer (raw material for protection against corrosion) and Umoe Ryving (blades) are other prominent counterparts

In conclusion, findings of the previous analysis confirm the presence/occurrence of both path dependency and creation dynamics (Garud & Karnoe, 2003): while a considerable number of countries are explicitly present within both time periods, newcomers can and do play a role during the second, growth, phase. Within the next section, we examine in a quantitative manner which factors account for growth dynamics during both phases. Relying on the insights generated by the historical accounts of the development of the wind industry in several countries, the following factors have been incorporated in the analysis: the presence of government policies, the role of universities and research institutes, R&D expenditures and the installed capacity (within the home market).

4. Factors contributing to technology dynamics of countries: data, method and results

Our second research question explores which distinctive characteristics of (national) innovation systems contribute in explaining technology dynamics in the wind industry. In addition, we examine whether and to what extent antecedents of performance are similar or different between the incubation and the growth phase of the industry.

The model is based on a panel data including the 24 countries selected in the previous section. We distinguish between two periods corresponding to the "incubation" phase (1978-1993) and the "growth" phase (1994-2007)^v. The dependent variable of the model is the total number of patents filled in the wind sector normalized by GDP. The explanatory variables (table 1) include:

> share of patents applied by universities and research institutes^{vi}.

Wind capacity installed at time t (IEA wind, GWEC), as a proxy of the expected MW installed at time t (Dechezleprêtre & Glachant, 2011)^{vii}. The development of a domestic market has played an important role in supporting wind power technology manufacturers (Lewis and Wiser, 2006). Also this variable has been normalized for size - MW installed divided by population;

- Wind R&D expenditure (IEA, 2010). Public R&D expenditure in wind energy is included. As reported by the IEA, these R&D expenditures mostly consist of tax credits on private R&D expenditures, which are received by companies once expenditures have been incurred^{viii}. This variable as well has been normalized by GDP. Historical data on public R&D expenditures are more readily available for countries, through the IEA database that has government R&D expenditure specifically for the wind sector. By contrast, a certain and comparable database with data on private R&D expenditure in the wind sector is not available.
- Policy. Some studies have recently analysed the impact of supportive government policies on wind technology (Buen, 2006; Lewis and Wiser, 2006; Johnstone et al., 2010; Dechezleprêtre and Glachant, 2011). IEA identifies five main types of policies, including investment incentives, tax measures, tariffs, obligations and tradable certificates; in this paper a factor analysis has been done on IEA types of policies in order to group those policies that are in practice highly correlated. As a result policies are modelled by means of three dummy variables, including 1) investment incentives, 2) taxes and tariffs and 3) obligations and trade permits. A "lag-effect" is assumed because commonly the innovation process require a certain time in order to produce a patent application (2 years).

Finally, we include the total number of patents filled by countries normalized by GDP to control for the technology intensity of countries.

Variable	Definition	Obs	Mean	Std Deviation	Min	Max
UNIV_INST_ PAT_SHARE	Share of patents applied by universities and other institutions respect to the total	384	.051	.12	0	1
HOME MARKET	MW of wind energy installed in the country respect to population	375	1.63	9.33	0	95
R&D /GDP	Government budget for wind energy /GDP	307	21.37	36.32	0	309.5
POLICY	Vector of dummy variables for policies:				0	1
	 Investment incentives 	384	.15	.36		
	 Taxes and tariffs 	384	.15	.35		
	 Obligations and permits 	384	.18	.13		

Table 1. Descriptive statistics of the explanatory, 1978-2007

1994-2007						
Variable	Definition	Obs	Mean	Std	Min	Max
				Deviation		
UNIV_INST_ PAT_SHARE	Share of patents applied by universities and other institutions respect to the total	336	.009	.07	0	1
HOME MARKET	MW of wind energy installed in the country respect to population	336	42.05	96.92	0	584
R&D /GDP	Government budget for wind energy /GDP	275	8.63	13.45	0	75.1
POLICY	Vector of dummy variables for policies:				0	1
	Investment incentives	336	.62	.49		
	 Taxes and tariffs 	336	.67	.47		
	 Obligations and permits 	336	.40	.47		

Source: elaboration with STATA software

Next we model the following equations by means of fixed effect (panel) regression models:

1) WIND PATENTS_{i,t*} = β_1 (UNIV_INST PAT SHARE _{i,t*}) + β_2 (HOME MARKET_{i,t*}) + β_3 (R&D/GDP_{i,t*}) + β_4 lag(POLICY_{i,t*}) + β_5 (TOTAL PATENTS_{i,t*}) + α_i + $\varepsilon_{i,t*}$

2) WIND PATENTS_{i,t**} = $\beta * *_1$ (UNIV_INST PAT SHARE _{i,t**}) $\beta * *_2$ (HOME MARKET_{i,t**}) + $\beta * *_3$ (R&D/GDP_{i,t**}) + $\beta * *_4$ lag(POLICY_{i,t**}) + $\beta * *_5$ (TOTAL PATENTS_{i,t**}) + $\alpha_{i,+} \epsilon_{i,t**}$

Where i = 1, ..., 24 indexes the cross-sectional country and $t^*= 1978 ..., 1993$ and $t^*= 1994..., 2007$; α_i , are the fixed effects capturing the country-specific heterogeneity. A negative binomial model with fixed effects is used in order to tests

and corrects for over-dispersion (Hausman et al., 1984).

The empirical results of the model for the two periods are summarised in table 2 and details are presented in the Appendix.

Table 2.	Estimated	coefficients

Independent Variable	Introduction phase	Growth phase	Growth phase
	1978-1993	1994-2007	1994-2007 (excluding
			R&D/GDP)
1. INST. PATENT	.3354658	2461662	.1404561
SHARE	(.2816556)	(.9330871)	(.7428787)
2. Government	. 0032775 **	0019452	/
R&D/GDP	(.0011146)	(.0050293)	
3. HOME MARKET	.0040331 (.0064697)	.0037894 ***	.0037257
		(.0004672)	(.0004705)***
4. INV.	2443837. (2405049)	0695088	0389392
INCENTIVES		(.0928429)	(.0896183)
5. TAXES &	.3072236 (.2277733)	.336425	.3458023
TARIFFS		(.1213721)*	(.1181114)**
6. OBLIG. &	247519 (.4731354)	0446022	0414935
PERMITS		(.1053167)	(.1002256)
OECD	110.4236 ***	49.06647 ***	54.20118
PATENT/GDP	(11.06868)	(9.044518)	(8.535484)
chi2	117.77	143.34	153.87
Prob > chi2	0.0000	0.0000	0.0000
Countries	20	22	24
† <.1.			

* p < .05. ** p < .01. *** p < .001.

Source: elaboration with STATA software

Our main findings reveal that the presence of characteristics of national innovation systems that have contributed to the development of the technology. Moreover, those factors vary between the two periods examined. In the incubation phase of wind technology, the significant and positive factors are the government wind R&D expenditure devoted to the technology and the overall propensity to patent (patent intensity). Quite surprisingly the development of the home market and support policies are not significant yet; this is likely due to the evidence that at the beginning

of a new technology, the development of the market is still small and uncertain, therefore, policies promoting the development of the home market are not affecting the development of technology. In the "growth" phase, by contrast, significant (positive) factors are different: just the development of the domestic market and certain types of policies (demand pull policies like taxes & tariffs). Quite surprisingly different types of supportive policies have not the same effectiveness in promoting innovation activity. This result is very interesting because there is still a debate, in European Union for instance, on the most effective supportive policies for renewable energies. For the second period (1994-2007), the model has been carried out again, without including the variable R&D expenditure respect to GDP, which is not significant anymore. By excluding this variable, it becomes feasible to include China and India for which R&D expenditure values are missing. The empirical results obtained confirm the outcomes of the previous model.

Therefore, the econometric model signal that the relevance and impact of antecedents vary considerably over time, between the first "stagnated" phase where a key role is played by government expenditures in R&D and the second more lucrative phase, where the development of the home market starts to affect technological innovation together with policies aimed at market development.

5. Conclusion

This paper examined the innovation trajectories of countries active in wind energy technology. Innovation is measured in terms of patenting activity over the period

1977-2008. Our data indicate that the technology trajectory follows a S-shape curve, characterised by a long "incubation" phase when the patent activity begins, grows slowly and then stagnates, followed by a "growth" phase when a rapid increase of patent activity is found.

The life cycle dynamics within this industry are further explored in order to address a number of questions on the level of innovation and technology dynamics. In particular, we investigate which technology dynamics occur at the country level and which factors contribute to their technological performance.

Our first results are promising for several reasons. The first reason is that the dataset used covers a long period of the technology activity, about 30 years, and the cross-country panel data includes almost all countries involved in the wind technology. Second, the distinction between two main phases of technology development allows to assess whether antecedents of technology performance are time-invariant or affected by life cycle dynamics. Finally some empirical results are very interesting as well. First of all, the evidence of a certain first mover advantage at country levels suggests that to be first mover in a technology field, although costly and uncertain, is instrumental during the growth phase. However, to be a first mover is not sufficient to ensure long term technology leadership; newcomers do enter the field and are able to gain a leadership position during the growth phase as well. Moreover, the econometric model shows that antecedents of technological performance vary according to the stage of the technology development. This observation bears important implications in terms of government policies: R&D policies (expenditures) present themselves as suitable during the incubation phase,

when the home market is still small; by contrast, during the growth phase, the growth of the home market and market supportive policies turn out to be influential. Therefore, our findings suggest that effective policies in the early stage of technology development are likely to be different from the ones relevant during growth phases and vice versa: policies commonly used to improve existent technologies are less relevant for stimulating technologies, that are still in an incubation phase.

Therefore the study is interesting because it increases the empirical knowledge on the literature concerning the innovation dynamics that occur when a new complex technology is developed and some dynamics that occur at country level. The main limitation of the study is that it refers only empirical case of wind technology, thus all the insights arisen in the study cannot be extended as general. Therefore future research should be undertaken. This includes covering new empirical cases. Results of new empirical cases could be useful to improve the methodology adopted and provide new tools for examining long-term innovation data.

Appendix: Results of the model

Independent Variable	1	2	3	4	5	6
1. UNIV. AND OTHER INSTIT. PATENT SHARE	1.0000					
2. HOME MARKET	-0.0728	1.0000)			
3. R&D	0.1207	0.1574	1.0000			
4. INV. INCENTIVES	-0.1366	0.1324	-0.0388	1.0000		
5. TAXES & TARIFFS	-0.0835	0.3341	-0.1445	0.2827	1.0000	
6. OBLIGATIONS & PERMITS	-0.1395	0.1892	-0.0854	0.3913	0.2337	1.0000

Correlation of the explanatory variables in the dataset

Results of the model for the Eq. 1: 1978-1993

Conditional FE negative binomial regression				Number	of obs	= 292
Group variable:	countrycod	e		Number	of groups	= 20
				Obs per	group: min	= 6
					avg	= 14.6
					max	= 16
				Wald ch	i2(7)	= 117.77
Log likelihood	= -961.637	71		Prob >	chi2	= 0.0000
Number patents	Coef.	Std. Err.	z	P> z	[95% Conf.	Interval]
Univ & Inst Pat	.3354658	.2816556	1.19	0.234	2165691	.8875006
R&D / GDP	.0032775	.0011146	2.94	0.003	.0010929	.0054621
Home market	.0040331	.0064967	0.62	0.535	0087002	.0167664
Investm. Incent	2443837	.2405049	-1.02	0.310	 7157646	.2269973
Taxes& tariffs	.3072236	.2277733	1.35	0.177	1392039	.7536512
Obligations	247519	.4731354	-0.52	0.601	-1.174847	.6798093
Total Patents	110.4236	11.06868	9.98	0.000	88.72941	132.1179
_cons	-1.279197	.1591637	-8.04	0.000	-1.591152	9672421

Results of the model for the Eq. 2: 1994-2007

Conditional FE r Group variable:	negative bind countrycode	omial regre	ssion	Number of Number of	obs groups	=	275 22
1	-				5 1		
				Obs per q	roup: min	=	6
					avq	=	12.5
					max	=	14
				Wald chi2	(7)	=	143.34
Log likelihood	= -965.4405	1		Prob > ch	i2	=	0.0000
5							
Number patents	Coef.	Std. Err.	z	P> z	[95% Con	f.	Interval]
+							
Univ & Inst Pat	2461662	.9330871	-0.26	0.792	-2.074983		1.582651
R&D / GDP	0019452	.0050293	-0.39	0.699	0118024		.007912
Home market	.0037894	.0004672	8.11	0.000	.0028736		.0047052
Investm. Incent	0695088	.0928429	-0.75	0.454	2514774		.1124599
Taxes& tariffs	.336425	.1213721	2.77	0.006	.09854		.57431
Obligations	0446022	.1053167	-0.42	0.672	2510192		.1618148
Total Patents	49.06647	9.044518	5.42	0.000	31.33954		66.7934

_cons | .1198118 .1915452 0.63 0.532 -.2556099 .4952336

Group variable: countrycode Number of groups = 24 Obs per group: min = 14 avg = 14.0 max = 14 Log likelihood = -1081.3974 Wald chi2(6) = 153.87 Prob > chi2 = 0.0000	Conditional FE n	egative bino	mial regres	sion	Number o	f obs =	336
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	Group variable:	countrycode			Number o	f groups =	24
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$					Obs per	group: min =	14
$max = 14$ $Wald chi2(6) = 153.87$ $Prob > chi2 = 0.0000$ $Mumber patents Coef. Std. Err. z P> z [95% Conf. Interval]$ $Mumber patents .1404561 .7428787 0.19 0.850 -1.315559 1.596472$ $Home market .0037257 .0004705 7.92 0.000 .0028035 .004648$ $Investm. Incent 0389392 .0896183 -0.43 0.6642145878 .1367095$ $Taxes& tariffs .3458023 .1181114 2.93 0.003 .1143083 .5772964$ $Obligations 0414935 .1002256 -0.41 0.6792379321 .1549451$ $Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042$ $_cons 0704807 .1731039 -0.41 0.6844097582 .2687967$						avg =	14.0
Wald chi2(6)=153.87 Prob > chi2Number patentsCoef.Std. Err. z $P > z $ [95% Conf. Interval]						max =	14
Log likelihood = -1081.3974 Prob > chi2 = 0.0000 Number patents Coef. Std. Err. z P> z [95% Conf. Interval] 					Wald chi	2(6) =	153.87
Number patents Coef. Std. Err. z P> z [95% Conf. Interval] Univ & Inst Pat .1404561 .7428787 0.19 0.850 -1.315559 1.596472 Home market .0037257 .0004705 7.92 0.000 .0028035 .004648 Investm. Incent 0389392 .0896183 -0.43 0.664 2145878 .1367095 Taxes& tariffs .3458023 .1181114 2.93 0.003 .1143083 .5772964 Obligations 0414935 .1002256 -0.41 0.679 2379321 .1549451 Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042 _cons 0704807 .1731039 -0.41 0.684 4097582 .2687967	Log likelihood	= -1081.3974			Prob > c	hi2 =	0.0000
Number patents Coef. Std. Err. z P> z [95% Conf. Interval] Univ & Inst Pat .1404561 .7428787 0.19 0.850 -1.315559 1.596472 Home market .0037257 .0004705 7.92 0.000 .0028035 .004648 Investm. Incent 0389392 .0896183 -0.43 0.664 2145878 .1367095 Taxes& tariffs .3458023 .1181114 2.93 0.003 .1143083 .5772964 Obligations 0414935 .1002256 -0.41 0.679 2379321 .1549451 Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042 cons 0704807 .1731039 -0.41 0.684 4097582 .2687967							
Univ & Inst Pat .1404561 .7428787 0.19 0.850 -1.315559 1.596472 Home market .0037257 .0004705 7.92 0.000 .0028035 .004648 Investm. Incent 0389392 .0896183 -0.43 0.6642145878 .1367095 Taxes& tariffs .3458023 .1181114 2.93 0.003 .1143083 .5772964 Obligations 0414935 .1002256 -0.41 0.6792379321 .1549451 Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042 cons 0704807 .1731039 -0.41 0.6844097582 .2687967	Number patents	Coef.	Std. Err.	z	P> z	[95% Conf.	. Interval]
Home market.0037257.00047057.920.000.0028035.004648Investm. Incent0389392.0896183-0.430.6642145878.1367095Taxes& tariffs.3458023.11811142.930.003.1143083.5772964Obligations0414935.1002256-0.410.6792379321.1549451Total Patents54.201188.5354846.350.00037.4719470.93042cons0704807.1731039-0.410.6844097582.2687967	Univ & Inst Pat	.1404561	.7428787	0.19	0.850	-1.315559	1.596472
Investm. Incent 0389392 .0896183 -0.43 0.6642145878 .1367095 Taxes& tariffs .3458023 .1181114 2.93 0.003 .1143083 .5772964 Obligations 0414935 .1002256 -0.41 0.6792379321 .1549451 Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042 cons 0704807 .1731039 -0.41 0.6844097582 .2687967	Home market	.0037257	.0004705	7.92	0.000	.0028035	.004648
Taxes& tariffs .3458023 .1181114 2.93 0.003 .1143083 .5772964 Obligations 0414935 .1002256 -0.41 0.679 2379321 .1549451 Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042 cons 0704807 .1731039 -0.41 0.684 4097582 .2687967	Investm. Incent	0389392	.0896183	-0.43	0.664	2145878	.1367095
Obligations 0414935 .1002256 -0.41 0.679 2379321 .1549451 Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042 _cons 0704807 .1731039 -0.41 0.684 4097582 .2687967	Taxes& tariffs	.3458023	.1181114	2.93	0.003	.1143083	.5772964
Total Patents 54.20118 8.535484 6.35 0.000 37.47194 70.93042 _cons 0704807 .1731039 -0.41 0.684 4097582 .2687967	Obligations	0414935	.1002256	-0.41	0.679	2379321	.1549451
_cons 0704807 .1731039 -0.41 0.6844097582 .2687967	Total Patents	54.20118	8.535484	6.35	0.000	37.47194	70.93042
	_cons	0704807	.1731039	-0.41	0.684	4097582	.2687967

Results of the model for the Eq. 2: 1994-2007, excluding R&D/GDP

Source: elaboration with STATA software

References

- Abernathy, W., Utterback, J., 1978. Patterns of industrial innovation, Technology Review 80, 40-47.
- Ackermann, T., Söder, L., 2002, An overview of wind energy-status 2002, Renewable and Sustainable Energy Reviews 6, 67–128
- Andersen, B., 1998, The Hunt for S-Shaped Growth Paths in Technological Innovation: A patent study.
- Astrand, K., Neij, L., 2011, An assessment of governmental wind power programmes in Sweden using a systems approach, Energy Policy, Article in press
- Buen, J., 2006, Danish and Norwegian wind industry: The relationship between policy instruments, innovation and diffusion, Energy Policy 34, 3887–3897.
- Bush, V., 1945. Science, The Endless Frontier. Public Affairs Press, Washington, DC.

comparison of wind industry policy support mechanisms, Energy Policy 35,1844-1857

- Danish Energy Authority, 1999, WIND POWER IN DENMARK TECHNOLOGY, POLICIES AND
RESULTSSEPTEMBER1999,
avialbaleavialbaleathttp://193.88.185.141/Graphics/Publikationer/ForsyningUK/WindPower99.pdf
- Dechezleprêtre A., Glachant, M., 2011, Does foreign environmental policy influence domestic innovation? Evidence from the wind industry, Cerna, Centre d'économie industrielle MINES ParisTech

- EPO, 2010, Project C456, TECHNOLOGIES OR APPLICATIONS FOR MITIGATION OR ADAPTATION AGAINST CLIMATE CHANGE; for more information see http://www.epo.org/news-issues/issues/classification.html
- Foxon, T.J., Grossa, R., Chase, A., Howes, J., Arnalle, A., Anderson, D., 2005, UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures, Energy Policy 33, 2123–2137.
- Freeman, C. 1988, Japan: a new national system of innovation?, in Technical Change and Economic Theory, G. e. al. Dosi, ed., Pinter Publishers, London.
- Garud R., Karnøe, P., 2003, Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship, Research Policy 32, 277–300.
- Global Wind Energy Council, (http://www.gwec.net/)
- Griliches, Z. 1957, Hybrid corn: An exploration in the economics of technological change, Econometrica, vol. 25, pp. 501-522.
- Hau E., 2006, Wind Turbines Foundamentals, Techinologies, Application, Economics, Springer_Verlaf Berlin Heidelberg 2006.
- Haupt, H., Kloyer, M., Lange M., Patent indicators for the technology life cycle development, Research Policy 36, 387–398
- Hausman J, Hall BH, Griliches Z,1984, Econometric models for count data with an application to the patents-
- Hendry C., Harborne, P., 2011, Changing the view of wind power development: More than "bricolage", Research Policy 40, 778-789

Hills, R., 1994, Power from the wind- A history of windmill technology, Cambridge University Press.

- http://www.globalchange.umd.edu/energytrends/germany/3/
- http://www.nasa.gov/vision/earth/technologies/wind_turbines.html
- International Energy Agency, 2004, Renewable energy-market and policy trends in IEA countries. IEA, Paris
- International Energy Agency, 2011, climate change policies (<u>http://www.iea.org/textbase/pm/?mode=cc</u>) International Energy Agency, 2011, R&D statistics (http://www.ieawind.org/)
- IPC classification, for more information see http://www.wipo.int/classifications/ipc/en/est/
- Kaldellis, J. K., Zafirakis, 2011, D., The wind energy (r)evolution: A short review of a long history, Renewable Energy 36, 1887 1901
- Kondratiev, N., 1925. The major economic cycles. Voprosy Konjunktury, English Translation Reprinted in Lloyd's Bank Review 129 (1), 28–79 (1978).
- Lewis, J.I., Wiser, R.H., 2007, Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms, Energy Policy 35, 1844–1857.
- Lundvall, B., Ed., 1992. National Systems of Innovation. Pinter, London.
- Meyer N.I., 1995, Danish wind power development, Energy for Sustainable Development, Volume 2, Issue 1, May 1995, Pages 18-25.
- Mowery, D.C. and Rosenberg, N. (1979) The Influence of Market Demand upon Innovation: a Critical Review of some Recent Empirical Studies. Research Policy, 8, 102-153.
- N. Johnstone, I. Hascic, D. Popp, 2010, Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts, Environ Resource Econ. 45, 133–155
- Nelson, R. 1993, National Innovation Systems: A comparative analysis Oxford University Press, New York.
- Nemet, G.F., 2009, Demand-pull, technology-push, and government-led incentives for non-incremental technical change, Research Policy 38, 700–709
- Oltra, V., Kemp, R., De Vries, F., 2008, Patents as a measure for eco-innovation, MEI project
- Popp, D., Hascic I., Medhi N., 2011, Technology and the diffusion of renewable energy, Energy Economics 33, 648-662
- R&D relationship, Econometrica 52, 909–938
- Ragwitz, M., Miola , A., 2005, Evidence from RD&D spending for renewable energy sources in the EU, Renewable Energy 30 (2005) 1635–1647.

Schmoch, U., 2007, Double-boom cycles and the comeback of science-push and market-pull, Research Policy 36, 1000–1015.

Schmookler, J. 1966, Invention and Economic Growth Harvard University Press, Cambridge, MA.

Schmookler, J., 1962. Changes in Industry and in the State of Knowledge as Determinants of Industrial Innovation. In: National Bureau of Economic Research, (Ed.). The Rate and Direction of Inventive Activity: Economic and Social Factors. Princeton University Press, Princeton, pp. 195–232.

Schumpeter, J., 1939, Business Cycles: A theorethical, Historical, and Statistical Analysis of the Capitalist Process, New York: McGraw Hill.

Vernon, R., 1966. International investment and international trade in product cycle. Quarterly Journal of Economics 80 (2), 190–207.

ⁱ For the advantage and disadvantages of patent as indicator of innovation in the renewable sector, see Oltra et al., Popp et al, 2010.

ⁱⁱ A typical example is given by General Electric (GE): by using the criteria of applicant country, then, all the patent applied by GE are allocate to the US; however, GE has some subsidiares abroad, in Europe for instance that come from acquisitions it made in the past; thus, by using the inventor country criteria this information on the place where technology is really produced is not lost.

ⁱⁱⁱ Innovations introduced by Nasa include steel tube towers, variable-speed generators, composite blade materials, partial-span pitch control, as well as aerodynamic, structural, and acoustic engineering design capabilities and demonstrated that there were considerable challenges for economic production of electricity in using much larger units, on the order of 1 MW or more, instead of the relatively small units as done up to 1980's

^{iv} During the so-called "California" boom, the danish wind turbine manufacturers ventured oversase, based on the confidence and experience they had in the domestic market. However, the crisis of US market and technology problems with the turbine installed overseas, had dramatic consequences in the danish industry: companies had to cope with financial problems and two large companies declared bankruptcy.

v The year 2008 is not included because patent data extracted in PATSTAT database were not complete.

vi Data on applicants have been obtained elaborating data extracted in PATSTAT database.

^{vii} An alternative method to measure the expected capacity installed is given by the weighted average of all past variations where the weights shrink as we move further toward the past (Dechezleprêtre & Glachant, 2011).

^{viii} For studies on the impact of R&D expenditure on renewable energies, see, Popp, 2002; Johnstone et al., 2010; Dechezleprêtre and Glachant, Ragwitz and Miola, 2005