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New technological path creation and the role of institutions in different geo-political spaces

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ABSTRACT

This paper analyses the roles of institutions in facilitating or impeding the creation of new technological pathways in different countries. It is argued that the successful invention, innovation and diffusion of new technologies require the co-evolution of relevant institutions. It is argued that informal institutions, through their impact on people's beliefs, perceptions and consequential behaviour, crucially influence whether formal institutions co-evolve with technological development and changing circumstances. At the same time, the rigidity of the pre-existing formal institutional arrangements impacts on whether agents can stimulate their co-evolution with the introduction of new technologies. These arguments are explored by comparing the creation of new wind power technologies in Britain and Germany since the 1970s.

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Introduction

This paper is focused on the roles of agents and the interactions between them and institutions in the creation of new technological pathways. This follows the recognition that, while there is some considerable agreement among scholars on the importance that should be attached to the roles of institutions with respect to economic and industrial development, there remains little analysis on either how or why institutions interact specifically with technological development on which much industrial development is based. In this paper, we seek to address this lacuna by examining empirically the significance of the co-evolution or lack thereof, of different types of institutions with technological development.

The main arguments in this paper are that first, new technological path creation is usually instigated by knowledgeable agents in the context of historical institutional arrangements. Second, the co-evolution of these institutional arrangements with the introduction of new technologies is important in enabling new technological path creation. Third, the national and regional differences in institutional ensembles and their co-

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evolution with technological change are a significant reason why new technological path creation finds more support in some countries and regions than others.

In the past two divergent views can be found offering explanations of how new technologies are created in the first instance. In much of literature on entrepreneurship, for example, the introduction of new technologies is attributed to the actions of exceptional and specific individuals (see Gartner, 1988) operating within the context of high degrees of freedom. In contrast, the canonical approach to path dependence theory emphasizes the probability of the evolution of technological trajectories towards lock-in because of contingent events, network externalities and increasing returns. These arguments provide little scope for unfettered freedom of action by entrepreneurs. Instead, new technological pathways are said to be created either by chance or as a result of severe external economic shocks (Arthur, 1989; David, 1985).

Martin (2010) makes the case for moving beyond the limitations of these two polarized arguments to explain the introduction of new technologies from an evolutionary perspective. There is a need to do this because many historical technological changes have been introduced in the absence of economic shocks and, even where external economic shocks have taken place, reactions to them by similar types of agent have been different in different places.

With respect to agency in the creation of new technologies, Garud and Karnøe (2001) and Simmie (2012) have argued that new technological pathways have often been created and diffused by reflexive and knowledgeable agents. This paper, therefore, seeks first to identify and explain, from an evolutionary theoretical perspective, the roles of agents in the processes of new technological path creation.

The second key question arising from the canonical exposition of path dependence exemplified by David (1985), Arthur (1989, 1990) and Vergne and Durand (2010) is that they have defined the concept in purely economic terms. But scholars such as Rip and Kemp (1998), Geels (2002) and Essletzbichler (2012) have argued that this approach is too narrow and that explanations of path-dependent technological trajectories should be situated in the wider system in which the technology is embedded. This argument is made clearly by Martin (2008) in saying that technological change is an inherently socio-cultural activity that is deeply dependent on the institutional setting within which it takes place (Martin, 2008).

Just as path-dependent technological trajectories are intertwined with their institutional settings so new path creation is also influenced by historical institutional arrangements and their co-evolution or failure to co-evolve with the introduction of new technologies. Institutions form an important filter for the perceptions of agents with respect to interactions between technological trajectories and their wider environment. Because of this filter, agents may or may not see possibilities for technological development, the need for institutional co-evolution and the potential for action. Co-evolution is said to occur as two or more parts of a field evolve together, not perfectly, but with slippage across time and space. In doing so, the co-evolving parts may both enable and constrain each other through feedback that can be negative or positive (Garud & Karnøe, 2001).

In the light of these arguments, this paper also seeks to explore the interactions between agents and institutions in the creation of a new technological pathway. This is illustrated by following through time the evolution of interactions between agents and institutional arrangements, as the new wind turbine technologies were being created in Britain and

Germany, and their subsequent co-evolution or lack thereof. This builds upon previous work on the evolution of the same technology in both Denmark and the U.S. (Garud & Karnøe, 2003; Simmie, 2012, 2013). Garud and Karnøe (2003), in particular, have illustrated the significance of differences in the confluence of agency and institutions in both the failure to create successful ‘breakthroughs’ in wind turbine technologies in the U.S., compared with the bottom-up approach of ‘bricolage’ adopted in Denmark. In this study, similar differences in success and failure between Germany and Britain are found. An explanation for such differences is sought in detailed analyses of the interactions between specific agents and institutions in the two countries.

Thirdly, therefore, it is argued that differences in institutional arrangements between countries and regions are a significant reason why new technological path creation takes place more easily in some localities than others. Evidence of the impacts of institutional differences at the level of nation states has been provided with respect to economic policy within different varieties of capitalism by Hall and Soskice (2001), and with respect to national systems of innovation by Lundvall (1995) and Freeman and Soete (1997). At the local level, Gertler (2010) argues that different ensembles of institutions contribute to the different pathways of economic development observed in different regional settings.

Following this introduction, the paper is divided into four substantive sections followed by a summary of the findings and conclusions. First, there is an exposition of the theoretical approach adopted to explain the interactions between agents and institutions in new technological path creation. Second, there is a short methodological section that outlines briefly how the original empirical data were collected and analysed. Third, this is followed by a three-part section comparing the historical path-dependent development of wind turbine technologies in Britain and Germany between 1970 and 2015, followed by individual parts that focus on the countries separately. In Britain, it is shown how institutional hysteresis impeded the development of the new technology. In contrast, in Germany, it is shown that institutional co-evolution was a key contributor to the creation of the new technological pathway in wind turbine technology. The fourth section shows the resulting impacts of these differing evolutionary histories that have produced different outcomes in the industrial landscapes of the two countries. A concluding section draws these findings together to argue that institutional differences and evolutionary processes provide a significant part of the explanation for both failures and successes in new technological path creation.

Institutions and new technological path creation

Little is known so far about the specific interactions between agents, institutions and new technological path creation. The literature on the roles of institutions with respect to innovation systems, for example, while recognizing their importance in principle, has not yet reached either a settled definition of institutions or agreement on what precisely their roles are in technological innovation.

Nelson (1993) regards institutions as the legislation and organization of education, training, funding and research frameworks that differ at the national level, and therefore form the basis of distinctive national systems of innovation. In contrast, Edquist and Johnson (1997) define institutions as behavioural patterns such as routines, norms,

shared expectations and morals. Yet another perspective is proposed by Lundvall and Maskell (2000). They argue that institutions develop from and co-evolve with solving specific problems in production through processes of interactive learning. With respect to agents, relational geographers have argued that institutions are made as a result of 'stabilizations of mutual expectations and correlated interaction' (Bathelt & Glückler, 2014, p. 341) between agents.

Despite these widely differing definitions of institutions, there is widespread agreement that technical change also requires complementary institutional change and that new technologies may not be supported by existing institutional arrangements but need to be so (Freeman & Perez, 2008; Nelson, 1998). As a result, for radical innovation to succeed 'institutional and regulatory changes must take place' (Rip & Kemp, 1998, p. 364).

There is also the widely held view that existing institutions often impede the introduction of new technologies. North, for example, views institutions as constraints. This leads him to argue that the concept of path dependence can be applied to both technological and institutional change (North, 1991). This view is echoed by Setterfield who suggests that institutions are evolving, non-optimal path-dependent phenomena (1993). Furthermore, he regards the relationships between institutions and the economy as naturally 'hysteretic' (Setterfield, 1993, p. 761).

Thus, in much of the original literature on the relationships between technology and institutions, it is argued that path dependence and lock-in of the former is deeply enmeshed with hysteresis and a lack of change in the latter. Institutions are, therefore, regarded as playing a significant role among the various forces underlying the path dependence of technological trajectories.

Due to its clarity of definition, North's taxonomy of institutions is adopted as the basis of the empirical work in this study. North's taxonomy distinguishes between:

1. 'Informal constraints (sanctions, taboos, customs, traditions, and codes of conduct)
2. Formal rules (constitutions, laws, property rights)' (North, 1991, p. 97)
3. 'Organisational forms of institutions (groups bound by some common purpose to achieve objectives)' (North, 1996, p. 5).

This taxonomy is also able to accommodate investigation of the scales or levels at which institutions are formed and the impacts of the differential levels of power associated with those different levels. Hudson (2004), for example, refers to processes of institution building that involve influences from macro-structures, such as the particular variety of capitalism found in different countries (Hall & Soskice, 2001), that are transferred to the individual level through institutions in a process of downward causation. At the same time, there are also processes of upward causation (Hodgson, 2003) in which micro-practices are translated into broader institutional arrangements that affect the macro-level. Differences of this nature are illustrated in the relationships between agents and institutions in the creation of their respective new pathways in wind turbine technology in Britain and Germany.

With respect to categories of agents that are relevant to the creation of new technological pathways, three types are identified for the purposes of operationalizing this study. These are:

1. Agents embedded in civil society: including citizens, consumers, activists in social movements, inventors, innovators and small-scale entrepreneurs.
2. Agents from the industrial landscape: including incumbent firms.
3. Policy-makers: including politicians, bureaucrats and government agencies.

In this taxonomy, it is possible for an agent to play more than one role. So, the same agent may be an activist in a social movement, work for an electricity-generating company and be an adviser to governments. There may also be tensions and inconsistencies in such multiple roles.

Some agents possess or develop the capacity to stimulate institutional change. Garud, Hardy, and Maguire (2007) identify what they call ‘institutional entrepreneurs’. These are actors who have an interest in particular institutional arrangements and who leverage resources to create new institutions or to transform existing ones. Social movements can also play a key role as collective agents of institutional change (Doblinger & Soppe, 2013; Vasi, 2011). In the context of the climate change debate, environmental groups help to bundle resources to gain an influential role in creating favourable social and institutional arrangements for the introduction of new technologies. Their primary mechanism is the building of pressure on formal governmental institutions.

In the light of the above discussions, the basic arguments of this paper may be summed up as follows. First, within a multi-layered perspective on the evolution of new technologies, these are argued to be created in the first instance by reflexive, knowledgeable agents. Second, these agents are at the same time both embedded in and in continuous reciprocal relationships with institutions. Third, the relevant institutions must co-evolve with the introduction of their technological innovations for them to diffuse through the economy.

From these arguments, it follows that path dependence and rigidity in both technological trajectories and institutions can impede the introduction and diffusion of technological innovations. Within the taxonomy of institutions, it is also argued, fourth, that informal institutions provide more fertile and less rigid environments for the generation of new ideas than formal and organizational institutions. The norms and beliefs that constitute informal institutions influence everyday behaviours and the willingness of individuals such as entrepreneurs to consider new ideas and to seek change. Thus, it is argued that informal institutions through their impact on the behaviours of agents influence the degree to which they press for formal institutional arrangements to co-evolve with technological developments or changing circumstances. At the same time, the degree of openness of formal and organizational institutions impacts on the ability of agents to instigate institutional co-evolution. These arguments are summarized diagrammatically in Figure 1.

Fifth, this conceptual framework is focused primarily on seeking to understand the need for institutional co-evolution with agent instigated technological change. But it is also recognized that the possibilities for the existence of variations in institutional ensembles at both different interaction and geographic levels offer potential ways of explaining how and why new technological path creation tends to take place in some geo-political spaces rather than others. The comparative analysis of Britain and Germany, presented in this paper, provides support for the argument that differences in the institutional ensembles, particularly at national geographic levels, help to explain observed differences in the creation or failure to create new technologies in the two countries.

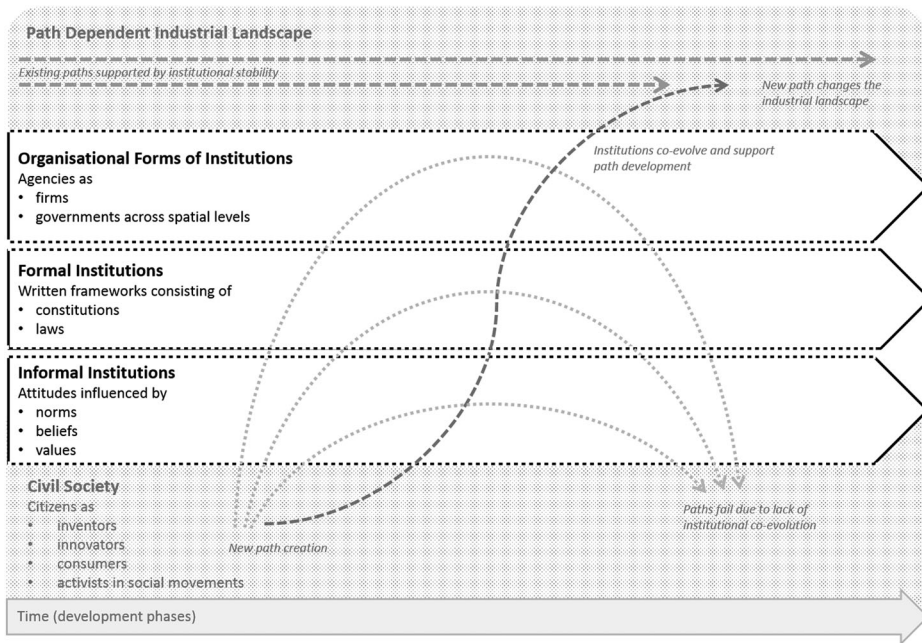


Figure 1. Institutions and new path creation.

Research methods

The above arguments have been applied to the analysis of the evolution of wind turbine technology in Germany and Britain. For reasons of manageability and focus, the study concentrates on the period from the earliest industrial development in the 1970s to about 2010. The shifting regime dynamics and changed landscape since then are also considered in the light of the findings.

The two countries were chosen because in relation to the number of patent applications they showed comparable rates of wind-related inventive activity in the early years (Essletzbichler, 2012; OECD, 2013). Companies in both countries were working at the technological frontiers of wind turbine development. Yet, by the early 1990s Germany was reaching for world leadership both in the industrial production and in the diffusion of this technology whereas no wind turbine producing manufacturer was left in Britain (Musgrove, 2010; Ohlhorst, 2008). They, therefore, constitute a leading and laggard case in wind technology-based industrial path creation.

Germany is globally known for its supportive renewable energy policies but the question why, despite similar technological pre-conditions, despite excellent natural resources, and despite being subject to the same external shocks, agents in Britain did not seek and succeed in putting in place a similar institutional support for this fledgling industry is the key interest of this study.

The qualitative, comparative research design enabled a focus on the perspective of participating agents on the development as such and on their interactions with the institutional setting. A total of 36 respondents were interviewed in a semi-structured format between January and November 2015. A pilot study with four academics with expertise in the fields of path dependency, institutions and the wind energy industry in Germany and

Britain was followed by the main fieldwork period consisting of 32 interviews with industry experts. Interviewees were chosen on the basis of their insight and expertise in the development of the wind energy industry, many were current or former holders of influential positions in organizations that shaped the industry or the institutional setting. Following preliminary assessment and the pilot study, a small number of key organizations and individuals were approached; further contacts were gained through snowballing.

The resulting textual data were used both immediately in a content analysis and textual analysis using Nvivo and as signposts towards relevant secondary datasets and sources. These data and the study of documents were then combined resulting in the analysis of the role of institutions for the path-dependent development of the wind energy industry in Germany and Britain

New path creation in wind power technology in Britain and Germany 1970–2010

Brief history

The following three-part section presents the findings of the analysis. The first of these gives a short comparative introduction to the historical path-dependent techno-industrial development of the wind energy industry in Britain and Germany between 1970 and 2010. The second and third sections present the findings on new technological path creation separately for the two countries.

The oil crises of the 1970s had left most countries in a position where the supply of energy sources was seen as insecure and a focus on locally available sources was supported. For many countries, including Britain and Germany, this meant a concentration on oil/gas and nuclear as well as coal (Simmie, Sternberg, & Carpenter, 2014). The common techno-economic paradigm was that energy generation had to take place on a large scale. This was reflected in the attitudes in both countries towards experiments in the creation of renewable forms of electrical energy generation. Government institutions in both countries initially adopted a ‘breakthrough’ approach to research in wind turbine technologies. Both provided research funding for the development of large-scale experimental turbines. In Germany, construction companies were supported by the Federal Research Ministry to build a very large turbine with a blade diameter of 100 m and an output of 3 MW known as the GroWiAn. The declared aim was to create a ‘breakthrough’ technology. The experiment was a financial and technological disaster. In Britain, the Department of Energy adopted a similar approach. A consortium of construction companies, Vertical Axis Wind Turbines, was funded to conduct R&D on large, ‘breakthrough’ vertical axis wind turbines. These hit technical problems and the funding was discontinued. Both governments, therefore, initially invested in attempts to produce ‘breakthrough’ large-scale plants and machinery (Musgrove, 2010).

[...] I think that is partly around market set-ups, so that is an institutional question, it’s partly also a question around cognitive lock-in of the people who were planning the electricity system in the UK and for them a small-scale, decentralised system wasn’t really on the horizon at all. (interviewee A4)

In Germany, complementary to the Federal Government, regional governments provided support for smaller schemes (Ohlhorst, 2008). In addition, early inventors were able to

secure funding from banks with a regional development remit and engaged individuals on the basis of a strong belief that alternatives to fossil fuels and nuclear energy had to be developed (Rave & Richter, 2008). This fostered a 'bricolage', incremental approach towards technological innovation that survived the withdrawal of Central Government funding as oil prices fell and stabilized.

This creates momentum. I know a lot of people, who, with this attitude invested in wind power, independent of whether they are going to become rich or not. (interviewee G15)

The continuation of the decentralized, incremental, bottom-up, 'bricolage' approach towards technological innovation in wind turbines put new German companies in a position, by the early 1990s, to reach for leadership in world markets in both the production and diffusion of wind energy technology. Later, in the early 2000s, the industry underwent the first wave of consolidation. Important early national players had to file for bankruptcy and/or were bought out by international competitors. Multi-nationals like Siemens entered the wind energy business (Bundesverband Windenergie, 2015; Ohlhorst, 2008).

In Britain, a few wind projects were realized in the early 1990s. Lacking comparable governmental support, the remaining British producers were not able to compete in a market with international producers (supported by their respective governments), and as a result, the first commercial wind farms in Britain were developed with foreign turbines (interviewee B8). By the early 2000s, government had discovered the political benefits of offshore wind farms and strongly supported development in this sector leading to the growth of a significant supply industry for offshore primarily in Scotland and to some extent in the North East of England (Dawley et al., 2014). Key steps in the historical development of the wind turbine industries in Germany and Britain are summarized in Figure 2.

Institutional hysteresis and impeded new technological path creation in Britain

Both this and the following section take up the theoretical argument about the important role of institutions and their co-evolution with technological trajectories and changing circumstances. They present the analysis of this process in each case country.

This section describes the aspects of institutional hysteresis which led to the failure of the wind turbine production path in Britain. When prompted about which formal institutions were most important for the development of the wind energy industry in general, interviewees mostly talked about the energy law and borrowing/finance policies. As explained above, early industrial support in Britain was directed towards large-scale development. The introduction of the Non-Fossil-Fuel-Obligation (NFFO) in the early 1990s, designed to support struggling nuclear plants in order to privatize them eventually, had a small tranche (less than 1%) for renewable energy projects (Taylor, 2016). Highly engaged civil servants used a window of opportunity when the NFFO was established to negotiate this support. While they succeeded on this occasion most of the time they were up against the entrenched structures and vested interests of Westminster. This reflects the important role that the historically grown, more centralized, more hierarchical and elitist structures in Britain played for the industrial development as they hindered their co-evolution by mindful agents like civil servants who had observed a need to change the formal institutional framework in support of this fledgling industry for a longer term benefit.

Germany	Britain
1970s: oil crises, focus on 'home' resources and investment in large scale development ('Breakthrough' approach towards technological innovation)	
1970s and 1980s: industry develops, sustained by funding by national government AND regions (decentralized, 'bricolage' approach to technological innovation)	1980s: small but competitive industry develops, sustained by government funding
Government(s) invest in small and large-scale schemes, additional funding from banks with regional development remit as well as ideologically driven individuals	Government funding for wind is discontinued on basis of study that considers wind 'long shot technology', mixture of lack of further funding options and costly incidents lead to re-orientation of firms to development or loss of interest altogether
Mid 1990s: Germany dominant wind turbine producer with solid home market	1990s: development of small number of projects but with foreign turbines (incl. the first offshore projects)
Early 2000s: industry undergoes consolidation period	Early 2000s: offshore gains government support and (supply) industry develops

Figure 2. Path-dependent techno-industrial development in Britain and Germany.

Several projects were realized with NFFO contracts, but this was too late for some British companies and competition on price made it difficult for others to compete against international companies that were supported by their governments (interviewee B8). Partly due to increasing international pressure and partly due to a need to occupy new political fields, the Renewables Obligation was introduced by the incoming Labour government (1997) in 2002. Again, the structure of the instrument did not support challengers to the incumbent industry but encouraged the existing large supply companies to diversify their portfolios. Both the NFFO and the Renewables Obligation (RO) were therefore structurally set-up to favour large-scale, established industrial agents (Mitchell, 2008). Further, interviewees reported that the sale of their Intellectual Property Rights (IPR) was strongly encouraged by the existing tax arrangements whereas the industrialization of their invention was not supported. This is evidence of structural support for agents to 'externalize' their inventions for a short-term financial benefit rather than to work on their exploitation within Britain for a longer term benefit through new path creation and development.

The governments have deliberately promoted and supported innovation through [tax. A]s an inventor I only have to pay 10% capital gains tax rather than 40%, when I sell my shares. That's a fantastic incentive. (interviewee B2)

When governmental support was discontinued inventors in Britain could not rely on individual supporters or local and regional banks to make up for the financial shortfall in the same way that their German counterparts could. Lack of funding opportunities beyond the initial government support was identified by interviewees as the key reason for the discontinuation of turbine production in Britain and therefore the failure of this newly created path.

With regard to organizational forms of institutions, the firms with activities in wind energy in Britain differed fundamentally in character from those in Germany. They were mostly large construction and engineering consortia with little or no interest in the actual development of an alternative energy source beyond the immediate technological challenge and the available government funding for it (Musgrove, 2010). So, when this funding discontinued there was a lack of individually motivated agents among the decision makers in those firms, who would have made sure that research and development in this sector continued. In combination with the above-mentioned lack of funding opportunities, this meant that the pathway towards an active home turbine industry was blocked.

Finally, in terms of the informal institutions, it is established that what were path changing external shocks in other countries, the nuclear incidents at Three Mile Island (1979) and Chernobyl (1986) had a much-reduced impact on attitudes in Britain. The same is true for the more recent incident at Fukushima (2011). The attitude towards this industry shows a relative stability in light of these shocks in comparison to Germany and other European countries (de Boer & Catsburg, 1988; Poortinga, Pidgeon, Capstick, & Aoyagi, 2014). Interviewees also spoke of a close relationship of the nuclear industry with government based on strategic recruitment of talent from elite universities. The friendships and relationships of trust established at university would endure and later result in powerful coalitions between those in government and those in the nuclear industry. Observers have also long spoken of a 'revolving door' problem between decision-making and industry in Britain (interviewee B11; Jones, 2014; Whitley, 1974).

These findings strongly support the argument that a lack of co-evolution of formal institutions slowed down and even hindered the development of a newly created wind turbine technology pathway in Britain. The table in Figure 3 summarizes the findings with regard to formal and informal institutions as well as organizational forms of institutions.¹

Institutional co-evolution enabled path development in Germany

This section describes how a process of institutional co-evolution enabled and encouraged path development in Germany. With regard to the formal institutional framework, interviewees identified the important role of the national administration for the development of this industry. Especially the introduction of a consumer subsidy in the form of a feed in tariff in 1990 is seen as a key step for the establishment of a market for wind energy. Funding was made available to schemes at all scales beyond just large-scale initiatives. In light of increased recognition of climate change and international agreements to address this challenge, it was decided that a comprehensive renewable energy law was necessary. Following delays and reluctance by the ministry for the economy in drafting this new policy, this was drafted by a coalition of parliamentarians from across the political

Path dependent institutions and hysteresis	Path failure
<i>Formal institutions</i>	
Energy law and finance/borrowing policy most talked about formal institutions	-> lack of funding opportunities beyond initial governmental support, key reason for discontinuation of turbine production
Sale of IPR encouraged through tax arrangement, industrialisation of inventions not supported	
NFFO (from 1990) and RO (from 2002) structurally favoured large scale projects and financially powerful agents	-> Little support for new entrants, lack of challengers
<i>Organisational forms of institutions</i>	
Character of firms: large engineering consortia with mainly commercial interest	-> lack of individual, ideological motivation amongst decision makers in firms
Governments: no agreement across party divides and even within parties over energy future ('flip flop policy')	-> instability for investment
<i>Informal institutions</i>	
External shocks like nuclear incidents not received in a similar way as in Germany and other European countries	-> attitude towards nuclear power relatively positive -> no passionate support for alternative means of energy generation, especially not amongst policymakers
Strong interwoven relationship ('revolving doors') between governmental and economic elite, including nuclear industry	-> capture of formal institutions and organisational forms of institutions

Figure 3. Institutional hysteresis and blocked new technological path creation in Britain.

spectrum. This is an example of a set of agents joining forces in response to the unsatisfactory work to address a societal challenge by an organizational institution (the ministry). The agents were able to form functional coalitions across the political divides using a shared vision for the future of energy generation in Germany. These cross-party alliances not only enabled institutional change but also guaranteed longer term stability.

In 2000, the renewable energy law (EEG) was presented which guaranteed fixed tariffs over a set period of time and therefore created a stable environment for investment (Ohlhorst, 2008). In addition, a pledge to exit from nuclear energy and its confirmation following the disastrous incident in Fukushima (Japan) in 2011 institutionalized the cultural aversion against nuclear energy felt by many citizens and led to the creation of the policy bundle known as *Energiewende*, which has received attention as a vanguard of renewable energy policy internationally.

Negative attitudes towards nuclear power were identified as a key factor in the development of the wind energy industry by 25 out of 36 interviewees. These attitudes make

up the most important informal institution. In combination with the international rise of a social and environmental movement, they galvanized agents across society into actions in support of technological development and institutional change (Vasi, 2011). Agents were personally driven to invent, invest, become activists demanding institutional change, or change the strategic outlook of their firms in light of the increasing recognition by consumers of the challenges posed by climate change. This shared sentiment united agents across society and across the political spectrum (Oelker, 2005; interviewee G1).

As mentioned above, the character of the firms active in wind energy in Germany differed strongly from that in Britain. The development of this path was driven by relatively small, independent firms and individually motivated agents. They were the carriers of this process of new path creation.

No major corporations were behind this. These were passionate individuals, ingenious inventors, convinced engineers, who really thought that this development was right. (interviewee G11)

This balance between institutional co-evolution with changing circumstances and institutional stability beyond short-term political, electoral cycles created the stable framework that enabled the development of the wind turbine path into a mature technology over the course of about two decades.

Figure 4 summarizes the key findings with respect to the role of institutions for the development of the wind energy industry in Germany.

Institutional Change and Co-evolution	Path Development
<i>Formal institutions</i>	
Introduction of consumer subsidy in 1990 and major amendment in 2000, funding made available to projects of ALL scales	-> highly engaged individuals created coalitions across political spectrum in support of a framework which was then maintained beyond electoral cycles
Pledge to exit from use of nuclear power	
<i>Organizational forms of institutions</i>	
Interviewees identified important role of national administration (introduction of subsidy as per the above)	-> decisive political support provided important stability for investors
Character of firms: small, independent companies, individually motivated agents (engineers – inventors, small business entrepreneurs)	-> path development driven and sustained by relatively small, independent, ideologically driven agents
<i>Informal institutions</i>	
Negative attitudes towards nuclear power addressed by 25/36 interviewees	-> combination galvanized agents to invent, invest, demand/instigate institutional change, change firm behaviour
International social/environmental movement in the 1980s	

Figure 4. Institutional co-evolution and new technological path creation in Germany.

Changes to the industrial landscapes in different geo-political spaces

Different configurations of institutional ensembles in Britain and Germany led to divergent path development resulting in different industrial landscapes. Institutions in Germany were co-evolved with technological trajectories and changing circumstances by personally motivated agents enabling the development of the wind turbine path and manufacturing industry. In contrast, institutional hysteresis resulting from a limited perception and motivation for change in Britain led to the relatively early failure of this pathway.

Being among the first movers and therefore a leading market for a substantial period has brought socio-economic benefit for Germany where an estimated third of all renewable energy systems-related employment in Europe is located (European Commission, 2014). 'Gross' (including the supply chain) employment in wind energy in Germany was about four times that of Britain – around 150,000 compared with 30,000 in 2015 (Global Wind Energy Council, 2015).

Despite some uncertainty in the home market, the relative competitive advantage and high quality of German wind energy products in the international market and the increasing significance of operations and maintenance expertise means that the growth of the sector can be expected to continue (Lehr et al., 2015). Meanwhile, in Britain, sub-sections of the industry experienced a slight decline in employment numbers. Reasons for this are the inconsistent signals from government and the resulting uncertainty (RenewableUK, 2015). Hence, a key challenge for both countries is to provide the institutional stability which creates the necessary certainty for investment. This is especially relevant in light of significant investments being made in emerging economies and the recent vote for Britain's exit from the European Union.

Summary and conclusions

The key objective of this paper has been to explain how and why the interactions over time between key reflexive agents and institutions in Britain and Germany contributed to the different technological pathways created in wind power technologies in the two countries. In the context of path dependence theory, the economies of both countries were subject to the same severe external oil price shocks of the 1970s. But while Germany responded by creating a new technological pathway in wind turbines over the following decades this was not the case in Britain.

During the 1970s, the energy systems in both countries were embedded in historically evolved and distinctive ensembles of informal, formal and organizational institutions. Policy-making agents in both countries were locked-in to the historical techno-economic paradigm of large-scale energy generation. As a result, the initial responses by Central and Federal Government agents, similar to the U.S., were to fund large engineering or construction organizations to build new, radical, large-scale prototype wind turbines. These experiments were either technical failures or discontinued after oil prices stabilized.

During this early period, two key institutional differences between Britain and Germany influenced the respective capacities of different agents in the two countries to create a new technological pathway. The first of these were differences in their formal constitutions. On the one hand, the British system of government was highly centralized and

hierarchical with only two main parties based on a 'first past the post' electoral system. This made it difficult for new social movements, in civil society, with alternative technological ideas to gain a foothold in formal government decision-making institutions.

On the other hand, after the Second World War, the German constitution was reorganized as a Federal system with powers devolved to the regional *Länder* and a proportional system of representation. This opened a number of avenues whereby agents could interact with formal institutions to encourage their support for new technological path creation. Within German civil society, like Denmark, there was already a growing belief in the need to create alternative technological pathways to those based on fossil and nuclear fuels. At the decentralized *Länder* government organization level, such agents could seek support both from regional government itself and from regional banks, with a local remit, for the development of small, energy schemes. Together, they provided niche development conditions for 'Tüftler' (engineering tinkerers) to experiment with small-scale wind turbines.

Thus, key institutional and agent differences already existed between Britain and Germany in the 1970s. At the level of informal institutions in Germany, individual inventors had already begun to believe in the need to create alternative technological pathways to fossil and nuclear fuels. At the level of organizational institutions, opportunities existed for them to interact with regional governments and banks to secure support for small-scale experimental wind turbines. Such interactions led to niche co-evolution of both the new technologies and their supporting institutional ensembles. Such agents and institutions were not present in Britain.

During the 1980s, the early niche developments of the new technology were subject to self-reinforcing elements in Germany. At the level of civil society and informal institutions, negative views of nuclear power were re-enforced by the sequence of reactor failures in America, Russia and later Japan. Such views began to find political expression due to formal institutional arrangements such as the system of proportional representation. These provided opportunities for upward causation with respect to changes in the development of industrial policies by the Federal and Regional governments.

In contrast, in Britain, centralized government institutions and large-scale industrial organizations tended to be populated by elite agents committed to nuclear power. In government, this commitment was partly based on the need for material for nuclear weaponry. In large industrial organizations, it was based on the profits to be made from construction and energy sales. This institutional nexus was reinforced by revolving door coalitions of pro-nuclear elite agents moving between government and industry.

A small experimental wind turbine industry was developed with the help of central government funding. But, in the tradition of the market-based approach to public policy prevalent in Britain, particularly under Margaret Thatcher, the fledgling industry was not seen as immediately profitable and so government funding was withdrawn. This illustrates the lack of avenues in the British institutional ensemble surrounding the creation of new technologies for upward causation based on new ideas, generated by agents in civil society, to gain traction among the formal and organizational institutions of government. This presents barriers to the development of new technologies from outside the dominant techno-economic paradigms.

The net result of these institutional differences was that by the 1990s British governmental organizations had withdrawn funding from large-scale industrialists. As a

result, they ceased R&D on new wind turbine technologies. Unlike Germany, there was no alternative set of small-scale engineering entrepreneurs or institutional supports to continue the development of the new technological pathway. In the favoured institutional conditions of free-market competition, British producers were unable to compete with foreign manufacturers benefitting from various forms of initial government support.

During the early years of radical new technological developments, some government support is often required to nurture the niche conditions needed as fledgling technologies make the transitions from experimental inventions to commercial innovations. In Britain, although some of the more technocratic civil servants recognized the need for institutional support for alternative small-scale forms of energy generation, they were unable to overcome the dominant institutionalized belief in price competition. The form of support introduced, because of the failure to privatize the nuclear industry during the 1980s, was minimal and aimed at dealing with a perceived 'market failure' rather than contributing to a techno-industrial strategy – only 1% of the NFFO was dedicated to renewables. This was the result of technocratic pressure from within central government rather than interaction between external agents, such as inventors, and government. Both the NFFO and later the RO continued institutionalized support for large incumbent firms capable of delivering large-scale projects.

In contrast, the introduction of a feed-in tariff in Germany did not discriminate in favour of large firms or specific technologies. Instead, it provided an effective support mechanism for the development of experiments in new, small and dispersed technologies. As such, it provided possibilities for interactions between inventors and activists from civil society and agents within the various levels of government institutions that led to the co-evolution of those institutions in support of the creation of the new technological trajectory. This evolution was given further impetus in 2000 demonstrating its ability to extend beyond short-term electoral cycles and to provide institutional support for medium- to long-term investment in new renewable energy technologies.

By the 2000s, the contrast between the co-evolution of long-term institutional support for wind turbine technology in Germany and the short-term market-oriented approach adopted in Britain was marked. In Britain, for example, because of the personal tax system, it was advantageous for inventors to sell their IPR in new technologies rather than to develop them into commercial innovations. This neither facilitated nor encouraged challenges to entrenched institutional and technological ensembles.

Meanwhile, in Germany, negative attitudes in civil society towards nuclear power had led to the rise of environmental social movements. Thanks, in part, to the institutional and governance arrangements, including devolved powers and proportional representation, politicians from across the political spectrum were persuaded to take notice of such external political pressures. Eventually, this resulted in significant formal institutional co-evolution in support of the use of renewable energy technologies, a pledge to phase out the use of nuclear power. This was formally expressed in the policy bundle 'Energiewende'.

In conclusion, it is argued that agents in Britain were limited by historically evolved formal and informal institutional ensembles that privileged downward causation from the centre, in their capacity to co-evolve institutions to support fledgling technologies. In contrast, agents in civil society in Germany were more able to stimulate upward causation and change in federal and regional institutions to encourage their co-evolution with the creation of new wind turbine technologies.

Further research

These findings contribute to the development of socio-institutional explanations of the creation of new technological pathways in the context of historically evolved path-dependent technological trajectories. They show, at least in the case of the creation of new wind turbine technologies, that successful new technological path creation requires a complex combination of agency and institutional co-evolution. This combination is required to evolve in the context of previously historically developed institutions in which current agents are themselves embedded. The case studies presented in this paper suggest that such evolutions may be more likely to be created, in the first instance, by incremental rather than radical innovation, in dispersed rather than centralized institutional ensembles.

These findings also have implications for explanations of why new technologies spring up in some geo-political spaces rather than others. At the level of the nation state, for example, it is relatively easy to identify differences in their historically evolved institutional arrangements. Given the argument that these represent important elements in previous path-dependent technological trajectories then differences in both these initial conditions and the possibilities for their subsequent co-evolution with technological innovation will form a significant part of why the geography of innovation is so uneven. Detailed analyses of institutional arrangements at lower levels of geo-political disaggregation than the nation state could also help to explain regional or even urban differences in new technological path creation.

The findings of this paper open a number of further research avenues. Among them is the unsettled issue of the definition of institutions and how to investigate them empirically. Significant differences remain between different schools of thought on what constitutes an institution and therefore what and which among them are key with respect to enhanced support for their co-evolution with the creation of technological pathways. The research reported here has pointed to the significance of 'informal' institutions as sources of challenges to existing techno-economic paradigms. Through their immediate effect on agents' attitudes and resulting behaviours, they are seen to fundamentally impact on processes of new technological path creation and institutional co-evolution. Again, the inherent place-dependency of the aspects that make up 'informal institutions' (e.g. local and regional culture), suggests that further studies investigating the role of local or regional institutional arrangements for path creation and development might lead to a deeper understanding of the geography of innovation.

The paper has also suggested that opportunities for 'upward causality' are important in translating those challenges into new paradigms. Further research is needed to explore in more detail the nature of these relationships and if they apply with respect to other technologies and therefore to technological innovation systems in general. The important question on the interaction of agency and structure has occupied sociologists for decades and is increasingly also discussed within Economic Geography. This is particularly relevant with respect to the question of how to bring about the co-evolution of new and supporting institutions to ensure the survival and diffusion of new technologies and industries. A key question here is how can existing institutional ensembles be converted from barriers to enablers of new technological path creation? Despite admiration for some of the long-term German organizational arrangements for technological

advancement, the adoption of variants in Britain has often led to disappointing results. A part of the explanation for these differences is likely to lie in, as yet, unexplained differences in the interactions between specific agents and institutions in the two countries. Further research is needed to identify and explore these phenomena.

Finally, the role of agency itself remains relatively underexplored in Economic Geography. Despite established recognition of the role of 'mindful' agents for path creation and increasing recognition of their crucial role in regional development and processes of diversification, agents themselves and the various roles, functions and types of agency are under-conceptualized. Both conceptual and in-depth empirical contributions are needed to better understand this most elementary component of economic development.

Note

1. Scotland represents a special outlying and devolved case within Britain where a lively supply industry for renewable energy and in particular for wind has developed in the years since the devolution of much of its strategic agenda through the creation of the Scottish Parliament in 1998 (Dawley et al., 2014; RenewableUK, 2016).

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