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Shaping factors in the emergence of technological innovations: The case of tidal kite technology

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ABSTRACT

The technological innovation systems (TIS) literature offers a detailed and dynamic understanding of factors that enable successful innovation. However, few studies analyze what determines where in space value chain elements are developed as a new technology is diffused on a large scale. The purpose of this paper is to show how the TIS approach can be used to identify and analyze factors that shape spatial trajectories of emerging technologies. It proposes an adapted analytical framework that expands the conventional focus on one-dimensional supporting and blocking factors, to shaping factors that incorporate the spatiality of innovation. The approach is illustrated by examining innovation in tidal kite technology. The analysis finds that a supportive local context in western Sweden during the infancy of tidal kite technology, together with the availability of competent engineers and business development professionals, promoted the formation of locally embedded knowledge and competence. This in turn created a spatial path dependency that made developments gravitate towards Sweden, although the lack of domestic markets has also increasingly driven an expansion of activity to other regions, in particular the UK. Moreover, the analysis shows that shaping, and not only stimulating, the growth of emerging TIS is an important challenge for regional policymakers, and highlights the need for international policy coordination. The paper concludes that analyzing shaping factors in the emergence of new TISs can yield important insights, some of which may be overlooked with a narrow analytical focus on supporting and blocking factors.

1. Introduction

Global warming due to anthropogenic carbon emissions is destabilizing the climate system in ways that may be devastating for human societies and ecosystems around the world (IPCC, 2014). Avoiding the worst consequences requires a rapid transition to a low-carbon energy system within decades (IPCC, 2014, 2012; Rockström et al., 2017). Governments on different levels play an important role in sustaining and accelerating this development, by promoting new technologies that may reduce the cost and increase the availability of renewable energy (Mazzucato and Semieniuk, 2017; UNEP, 2017).

In the sustainability transitions literature, which encompasses several interrelated and overlapping concepts, models and frameworks (Coenen and Díaz López, 2010; Markard et al., 2012), the technological innovation systems (TIS) framework is often described as an appropriate approach for analyzing emerging technologies and informing policy interventions (Binz et al., 2014; Jacobsson and Bergek, 2011; Markard et al., 2015; Truffer, 2015). The TIS framework conceptualizes technology development and diffusion as the gradual development of sociotechnical system structures along the value chain for a new technology (Bergek et al., 2008a, 2008b; Hekkert et al., 2007; Hekkert and Negro, 2009). This process is understood by analyzing functions that describe how actors mobilize, develop and combine resources such as knowledge, financial capital, legitimacy and markets (Bergek et al., 2008a; Hekkert et al., 2007; Hekkert and Negro, 2009). The TIS literature focuses on analyzing strengths, weaknesses and dynamics in these functions, in order to identify factors that support and block structural development, and that can be used to guide policymakers. However, few TIS studies attempt to identify what determines where in space structural development occurs. This may be due to a neglect of the geography of innovation, which has been pointed out by a number of scholars (Binz et al., 2014; Coenen et al., 2012; Markard et al., 2012; Raven et al., 2012; Truffer and Coenen, 2012), but also connected to a general emphasis on factors that support and block rather than shape TIS growth.

The spatial distribution of structural development along the value chain is important because it determines where localized benefits are created as a renewable energy technology is diffused on a large scale.[1]

Abbreviations: TIS, technological innovation systems; R&D, research and development; RD&D, research, development and demonstration

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[1] The successful development and diffusion of new technologies also creates global benefits that impact the whole planet, such as mitigation of climate change.

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Regions where power is produced may enjoy strengthened energy security and reduced pollution, while enabling supply industries give rise to new jobs, increased tax revenues and knowledge spillovers to other sectors. In a globalized economy, however, it is far from certain that these benefits arise in the same region that originally enabled technological innovation, by making public investments and implementing supportive policies (Binz et al., 2017; Bunnell and Coe, 2001; De Backer et al., 2017; Ernst, 2002; Lovdal and Moen, 2013; Quitzow, 2015). The spatial configuration of value chains can develop in different and unexpected ways, which leads to uncertainties that may discourage policymakers from supporting new technologies and result in a slower global response to challenges such as climate change (Binz and Truffer, 2017). A better understanding of how spatial trajectories form as a result of innovation dynamics in early development stages can potentially reduce these uncertainties. In addition, it may enable the design of policies that not only stimulate the development of new technologies, but also ensure, or at least increase the likelihood, that key value chain elements are developed domestically.

The purpose of this paper is therefore to show how the TIS approach can be used to identify and analyze factors that shape spatial trajectories of emerging technologies. We propose an adapted analytical framework that distinguishes between regional sub-systems within a global TIS, and explains where structural development occurs by differences in resource formation processes at the sub-system level. Analyzing these processes allows for identifying shaping factors, which may reduce uncertainties and enable the design of more appropriate policies.

We illustrate the adapted analytical framework by analyzing the emergence of tidal kite technology, which is intended to produce electricity from low-velocity tidal streams and ocean currents (Minesto, 2016a). The technology was invented in 2004 and has since then been developed mainly by Swedish actors. Small-scale prototypes have been tested in tank, sea and ocean environments, and preparations for deploying the first full-scale demonstration are ongoing. A distinguishing feature of tidal kite technology is its dependence on suitable tidal streams or ocean currents that simply do not exist in Sweden. This rules out domestic deployment both for testing and commercial purposes (Andersson, 2013), which is why key actors from an early stage were forced to act on an international level to access funding, supportive policy schemes, and suitable locations for testing and demonstration (Andersson et al., 2017). It is accordingly an extreme case (Flyvbjerg, 2016), where international linkages and dynamics can be expected to be particularly extensive and decisive, which makes it appropriate for illustrating our adapted analytical framework as well as for learning more about factors that shape spatial trajectories.

After this brief introduction, we proceed in Section 2 by establishing a theoretical foundation and developing our analytical framework. Section 3 then describes the research design, while Section 4 analyzes the emergence of tidal kite technology. Thereafter, in Section 5, we discuss our findings, identify policy implications, highlight our contributions and suggest avenues for future research. Finally, our conclusions are presented in Section 6.

2. Theoretical foundation and analytical framework

As a result of criticism towards the traditional market failures approach to justifying and designing policy intervention in the economy (Jacobsson et al., 2017; Bleda and Del Rio, 2013; Jacobsson and Johnson, 2000; Lazonick and Mazzucato, 2013; Metcalfe, 1994; Smith, 2000), the sustainability transitions literature, which attempts to understand fundamental transformations of sociotechnical systems, has proposed a number of alternative and somewhat overlapping conceptual frameworks for analyzing technological innovation (Markard et al., 2012). The literature commonly views the economy as a dynamic system, characterized by increasing returns and positive feedback (Bergek et al., 2008b; Geels, 2005). Innovation is understood as a collective endeavor, involving a multitude of actors that engage in complex and cumulative learning processes (Bergek et al., 2008a; Markard and Truffer, 2008). The influence of institutions on the innovation process is emphasized and often put central to the analysis, and phenomena such as interdependence, path dependency and lock-in are widely acknowledged (Arthur, 2009; Carlsson et al., 2002; Geels, 2005; Unruh, 2000). In addition, policy intervention is seen as justified and desirable for successful innovation, and studies are often geared towards informing policymaking (Bergek et al., 2008a; Jacobsson and Johnson, 2000; Klein Woolthuis et al., 2005; Weber and Rohracher, 2012).

Within this field, the TIS approach is often promoted as appropriate for analyzing emerging technologies from a policy perspective (Binz et al., 2014; Jacobsson and Bergek, 2011; Markard et al., 2015; Truffer, 2015). The remaining part of this section describes the TIS approach in more detail, motivates the need to focus more on the process of shaping, particularly in the spatial dimension, rather than staying with the one-dimensional question of fast growth versus slow or blocked growth, and outlines an analytical framework that makes this possible.

2.1. The technological innovation systems (TIS) approach

The TIS approach is based on evolutionary economic theories (Markard and Truffer, 2008) and has strong linkages to other innovation systems approaches that focus on nations (Lundvall, 1992), regions (Cooke et al., 1997) or sectors (Malerba, 2002). Building on the notion of ‘technological systems’ proposed by Carlsson and Stankiewicz (1991), and later contributions by among others Jacobsson and Johnson (2000), Hekkert et al. (2007) and Bergek et al. (2008a, 2008b), a TIS can be defined as a sociotechnical system that enables the development, diffusion and utilization of a new technology. It exists in a context of other emerging technologies, established industry sectors and broader societal systems such as the political, financial and education systems (Bergek et al., 2015). Defining a TIS thus involves setting a system boundary in the sociotechnical dimension as well as specifying its spatial and temporal reach (Hillman and Sandén, 2008).

As a sociotechnical system, a TIS consists of social and technical components that can be categorized and described in somewhat different ways (Bergek et al., 2008a; Geels, 2002; Hughes, 1987; Sandén and Hillman, 2011). The conceptualizations available in the literature arguably attempt to capture the same underlying phenomenon; namely that the world seemingly consists of physical objects that are either inert (i.e. artifacts) or have some kind of individual or collective agency (i.e. actors). These physical objects interact systemically under the influence of rules that may be socially constructed (i.e. institutions), and exist as beliefs and values embedded in actors or as mechanisms and codes embedded in artifacts, or constitute fundamental characteristics of nature (such as the force of gravity). This paper therefore adopts the view that artifacts, actors and rules are the fundamental structural components of a TIS (see Sandén and Hillman (2011) for a similar view).

Artifacts include physical objects that constitute or enable the development of the technology in focus (i.e. machine components, testing infrastructure etc.) as well as ones in which codified knowledge is embedded (i.e. papers, hard drives etc.). Actors comprise firms, universities, research institutes, governments, public agencies and other organizations, but also individuals that may act as entrepreneurs, experts or parts of larger groups. Finally, rules consist of fundamental forces and characteristics of nature together with socially constructed regulative, normative and cognitive procedures. The latter are embedded in formal laws, regulations and standards as well as in informal norms, values and beliefs. In addition, it should be noted that networks are often highlighted as a structural component in the literature (Bergek et al., 2008a; Jacobsson and Johnson, 2000). Here, however, they are viewed as a system property, emerging from the interplay of artifacts, actors and rules, which is by no means intended to downplay their