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The geographic origins of radical technological paradigms: A configurational study

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ABSTRACT

History and place matter for the emergence of new technological paradigms. However, limited empirical evidence exists that reflects the characteristics that support or hinder the development of radical technologies within regions. In this study, we theorize geographic regions as distinct socio-economic-political systems with different resources for radical technological development. We integrate evolutionary economic geography and technology management literatures with universities positioned as key drivers for radical technology development within regions. We use the creation of a university research center for a radical technological design as evidence of new technology paradigm emergence. The framework explains the influence of intellectual, industry, social, and political characteristics on the geographic origins of radical technological paradigms. It is tested using a configurational approach – fuzzy set qualitative comparative analysis – in the emerging fuel cell technology context, which is a radical paradigm for energy generation. The sampling frame includes 48 metropolitan statistical areas in the United States. The findings reveal five unique configurations that lead to the presence of a new paradigm within regions, and five different configurations that are associated with its absence.

1. Introduction

Society advances when new technologies make it possible to complete tasks more efficiently, more cost effectively, or in entirely different ways than existing technologies (Anderson and Tushman, 1990; Hagen, 1962; Schumpeter, 1934). Often these technologies are developed from engineering or scientific principles that differ significantly from incumbent technologies (Henderson and Clark, 1990), and are thus radical departures from technologies that are commonplace in the market (Shane, 2001a). Radical technologies represent new technological paradigms, which are research programs that include "a set of procedures, a definition of the "relevant" problems and of the specific knowledge to their solution" (Dosi, 1982, p. 148). They are patterns of "selected technological problems, based on selected principles derived from natural sciences and on selected material technologies" (Dosi, 1982, p. 152). New designs challenge the future potential of incumbent designs by outperforming them on key dimensions (Schoenmakers and Duysters, 2010), frequently irrevocably transforming the economic landscape in the process. History confirms that radical technologies have displaced incumbent technologies in industries as diverse as electricity (Hargadon and Douglas, 2001), transportation (McGrath, 1998; Rao, 2004), recording media (Funk, 2007), and typesetting (Tripsas, 1997). Perhaps more importantly, recent evidence shows that radical technologies continue to affect many markets at increasing rates (Funk, 2008; Rao, 2004).

The increasing occurrence of radical technologies places importance on understanding how such change-inducing technologies originate. Schumpeter described the emergence of transformational technologies as endogenous, arising from "within the socio-economic system" (Boschma and Martin, 2010, p. 5), which Storper and Walker (1989) and others have described as being geographically bounded. Local conditions are "important to the (. . .) emergence of radically new technological and innovation trajectories" (Martin and Sunley, 2010, p. 83) because regions hold ". . .an extraordinarily complex manifestation of societal relations and productive activity" (Storper and Walker, 1989, p. 1) with the potential to constrain or enable future economic activity. While the field of economic geography has established a solid foundation for the geographical underpinnings of socio-economic systems, there

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is much to learn about how these factors influence the geographic origins of radical technological paradigms (Tanner, 2014). In fact, recently scholars have called for analyses that account for the co-determination of social and technological configurations, which are sets of heterogeneous elements that align to produce an outcome, in order to explain new technology path development (e.g., Gilbert, 2012; Truffer and Coenen, 2012). Indeed, answering the question of "where new paths come from, and why they emerge where they do" is said to be a matter requiring critical attention (Boschma and Martin, 2010, p. 8).

This study takes an important step toward contributing this knowledge to the field. We integrate the evolutionary economic geography and technology management literatures to create a framework of regional demand-pull and technology-push factors that combine to contribute to new technological paths (Dosi, 1982). The specific question addressed in this work is – what regional configurations are responsible for the geographic origin of new, radical technological paradigms? A configuration is defined as a specific combination of conditions (Ragin, 2008) or a "specific combination of factors... that produces a given outcome of interest" (Rihoux and Ragin, 2009, p. xix). Because socio-economic systems can be configured in various ways (Truffer and Coenen, 2012), and new technological paths can be linked to diverse regions (Tanner, 2014), we employ a configurational method to understand the regional characteristics (i.e., combinations of regional conditions) associated with new path development. We have identified regions where *new paradigms* that are *radical* relative to current industrial activity are originating, and examined the regional characteristics present before the new paradigm became evident. Thus, this work represents a significant departure from the strand of research that either seeks to explain the agglomeration of current economic activity, or to identify common attributes (e.g., Almeida and Kogut, 1999; Jaffe et al., 1993; Pouder and St. John, 1996; Saxenian, 1996) or the birth (Zucker et al., 1998b) or performance (Sorenson and Audia, 2000; Stuart and Sorenson, 2003) of firms within clusters. This research extends Tanner (2014), Madsen and Andersen (2010), and similar work that identifies where new technological paths are locating and what factors contribute to their emergence.

The radical technology that we focus on is the emerging fuel cell technology. Our framework assesses how combinations of regional intellectual, industry, social, and political characteristics (Storper and Walker, 1989) influence whether radical technological paths originate within a given region. We use university research centers as evidence of emerging activity for the radical technology. To adequately model the possibility of equifinality – the situation where several unique configurations lead to the same outcome of interest (Fiss, 2007) – we apply a set-theoretic approach using fuzzy set qualitative comparative analysis (fsQCA). The theory and findings herein provide a nuanced understanding of the regional characteristics that are associated with radical technology origins.

2. The geographic origins of radical technological paradigms

The study of innovation and economic activity within regions has a long tradition (e.g., Marshall, 1920), but is experiencing renewed momentum in the literature. This body of work describes geographic space as unique collections of social, economic, and political characteristics (Storper and Walker, 1989), with various configurations that support certain forms of industrial activity. In fact, Martin (2010, p. 20) explains that,

> "Innovation is indeed often a highly localized phenomenon, dependent on place-specific factors and conditions. Those factors and conditions are not simply "accidental" or random but are often the product of and reflect the economic, social, cultural, and institutional conditions inherited from the previous industrial and technological histories of a locality."

Martin (2010, p. 15) further explains that "any particular existing social–political–economic structure is, in effect, a system of resources and properties that actors can recombine and redefine, in conjunction with new resources and properties, to produce a new structure" (Martin, 2010, p. 15). In other words, regions differ in their capacity for supporting new technological forms (Madsen and Andersen, 2010; Tanner, 2014), and thus, geographical 'space' plays an important role in new technological path creation (Bottazzi et al., 2007). New technological–industrial paradigms are influenced by enabling and constraining, exogenous (such as government policy) or endogenous (i.e., region-specific) factors, and are also partly agent-driven (e.g., Staber, 2010) – the result of deliberate efforts to establish new trajectories (Martin and Sunley, 2010). In fact, many technological advances of this century have emerged from the efforts of organized R&D (Dosi, 1982). Thus, within regions, technologies, industries and accompanying institutions evolve along unfolding trajectories, which requires a multi-level perspective to assess from where new activity will originate (Truffer and Coenen, 2012).

A radical technology represents a new technological form with an architectural design that differs fundamentally from incumbent technological systems. Its difference relative to the incumbent technology increases the difficulties associated with its creation and acceptance in the marketplace. Their unique nature requires commitment to long development times (Fuchs, 2010) to allow the best technological alternatives to emerge (Bresnahan and Malerba, 1999). Long time frames suppress incumbents' ability to meet short-term goals (Santoro and Chakrabarti, 1999). Not surprisingly, prior research shows that radical technologies rarely originate from industry incumbents (Anderson and Tushman, 1990; Shane, 2001a). In some cases, radical technological shifts have emerged from strategic government-sponsored mission-oriented policies where radical, new technologies are developed for national defense or pride purposes (Basalla, 1998; Nemet, 2009; Spencer et al., 2005). Mission objectives are implemented to connect big problems to large scientific endeavors (Ergas, 1987), and often evolve into technological leaps (Branscomb, 1993). Therefore, radical technologies sometimes emerge from deliberate efforts to initiate new technological forms.

Some studies suggest that public–private initiatives are commonly used to promote new technological paradigms (Madsen and Andersen, 2010). In fact, historical evidence shows that research universities have often fulfilled this important role (Basalla, 1998; Mazzoleni, 1999). Perez and Soete (1988) argued that universities are essential for contributing to the knowledge base that is needed for new technological paradigms. Tanner (2014) also shows that universities were important factors behind new technology emergence in Europe. Therefore, we focus on early university developers of radical technological paradigms, and their corresponding regions as those from which radical paradigms originate.

2.1. Universities, intellectual resources, and the emergence of radical technological paradigms

University environments are important for radical technology development because they offer scientists the intellectual freedom that permits them to "change the nature of the problem they pursue, the material technology employed, and/or the heuristics used to approach the problem" (Nicholls-Nixon, 1995, p. 5). Academic freedom positions scientists to solve problems in unique ways, making them important catalysts behind industrial technological paradigm shifts (Nicholls-Nixon, 1995). Research universities have