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Patterns of innovation and organizational demography in emerging sustainable fields: An analysis of the chemical sector

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ABSTRACT

This paper examines the patterns of environmental innovation in the chemical sector and focuses in particular on detecting whether the rise of sustainable chemistry technologies (SCT) has stimulated the emergence of new organizations. This question is important to assess the extent to which SCT are sustaining the technological advantage of industry incumbents or are creating opportunities for new firms aspiring to develop radically new environmental innovations. We found that SCT still represent a relatively low proportion of chemical technologies and that they have not stimulated, in a significant way, the emergence of new firms. However, the importance of new firms has grown in the last 20 years and their technologies seem to have a higher potential of radicalness than incumbents' technologies. This indicates that, although incumbents' advantage remains strong, a small group of young firms has started to weaken such advantage. Moreover, the important role played by research organizations in generating SCT may signal that technological opportunities are expanding and that some governments, in particular the US government, are committed to develop SCT. These results suggest that, if supported by effective policies, technological ferment in the field, which at the present appears still limited, has a potential of growth.

1. Introduction

Our current modes of production and consumption have created severe problems in terms of both depletion of natural resources and environmental pollution, and therefore are widely considered unsustainable. Environmental innovation has the potential to trigger a transition toward more sustainable economies. Such potential, however, critically depends on the ability to generate radically new environmental technologies, capable to achieve significant environmental benefits. Given the magnitude and pervasiveness of environmental problems we are facing, it is likely that incremental environmental improvements in existing technologies will not suffice to cope with prevailing sustainability challenges (Kemp et al., 1998; Dosi and Grazzi, 2009; Markard et al., 2012). Yet, developing radical technologies often requires large, long-term investments, and, above all, it is a risky process because of the high uncertainty surrounding the technological and commercial output of these innovations. Moreover, by definition, radical innovations have a strong disruptive impact on exiting technologies, competences, organizational structures and even, in some cases, on broader economic and institutional structures. Therefore, they may meet the resistance of vested interests (Kemp et al., 1998).

Using patent data, this article analyzes the patterns of environmental innovation in the chemical sector, a sector that is highly important for environmental sustainability due to both its economic relevance (in terms of world economic growth and employment) and its strong environmental impact (polluting and nonrenewable feedstocks like petroleum, toxic wastes, non degradable products, industrial accidents). In this context, we are especially interested in detecting whether the rise of sustainable chemistry technologies (SCT) is stimulating the emergence of new organizations, namely new firms and research organizations (universities and government agencies). Answers to this question are important to assess the extent to which SCT are sustaining the technological advantage of incumbent firms, strengthening their position in the industry, or are disrupting established technologies and competences, creating opportunities for new firms aspiring to develop radically new environmental alternatives. Although with different perspectives, various theoretical approaches (Anderson and Tushman, 1990; Christensen, 1997; Kemp et al., 1998; Breschi et al., 2000; Markard et al., 2012) associate the emergence of new firms to an era of "technological ferment", a turbulent period characterized by high technological opportunities, the "creative destruction" of established technologies, the erosion of incumbents' advantage and the emergence of radically new

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products and processes. The absence of new organizations and the dominance of incumbents is instead associated with improved variants of existing products and processes, incremental or competence-enhancing changes, sustaining innovations and established regimes. The general explanation advanced by these studies is that incumbents possess specific knowledge (Breschi et al., 2000), competences (Anderson and Tushman, 1990), complementary assets (Geels, 2011), managerial practices and values (Christensen, 1997) that make either difficult or disadvantageous for them investing in radically new technologies. Leading firms may not have the competences for developing radically new technologies because they are burdened with the legacy of prior technologies and ways of operating (Tushman and Romanelli, 1985). Moreover, incumbents may not be interested in stimulating a competing technology and may not be willing to risk their core competencies, technologies and production facilities becoming superfluous (Kemp et al., 1998).

Based on these studies, we propose that observing a high number of new firms engaged in the development of SCT may signal that we are experiencing a period of technological ferment, characterized by exploration, experimentation and competition among different technological alternatives that try to break with exiting knowledge and create radically new environmental innovations. A growth of university innovative activity also may be symptomatic of technological turbulence, as universities develop more basic technological knowledge (Trajtenberg et al., 1997), which increases technological opportunities and lowers barriers to entry (Malerba, 2002). A sustained innovative activity of government agencies should signal the support of involved governments to develop SCT, which may be critically important for the emergence of radical innovations too. On the contrary, the dominance of incumbents' technologies should indicate that we are experiencing a period of stability, characterized by incremental changes and the "creative accumulation" of existing technologies, capabilities and resources. In this scenario, incumbents elaborate and incrementally adapt their current products and processes in order to reduce their environmental impact.

To obtain systematic evidence on the emergence of new organizations in the field of SCT, we first build an original dataset of patents relating to SCT, and analyze the main trends emerging from patent statistics. We then use network analysis algorithms to map the main clusters of SCT and identify the technological areas where organizations are concentrating their research efforts. Finally, we detect the demography of organizations that generated SCT clusters. With organizational demography we intend the organization type (public versus private), its age, nationality, and some properties of their knowledge base that are expected to capture the degree of radicalness of their technologies. This allows us to determine the respective role played by incumbents, new firms and research organizations in generating SCT, and to provide an indication of their respective potential to develop radically new environmental innovations. The rest of the paper is organized as follow. Section 2 is an overview of the theoretical approaches outlined above, the main characteristics of the chemical sector and the most important sustainable initiatives in the chemical sector. Section 3 illustrates data and methods. In Section 4, we present and discuss the main trends emerging from patent statistics, the analysis of SCT clusters and the study of organizational demography. In Section 5 we conclude.

2. Background

2.1. Background literature

Innovative activities involve a variety of actors, including large incumbents, new and usually smaller firms, as well as other types of organizations such as universities and government agencies. The important role played by universities and government agencies as major source of new scientific and technological knowledge has been highlighted by many studies (e.g., Nelson, 1993). Compared to firms, universities generate more basic technological knowledge (Trajtenberg et al., 1997), which increases technological opportunities and lowers barriers to entry (Malerba, 2002). As to firms, a long tradition starting with Schumpeter (1911/1983, 1942/2014) has studied the respective roles and capabilities in innovative activities of incumbents and new firms. Schumpeter first highlighted the role of individual entrepreneurs in generating innovation and creating early industrialization (Schumpeter, 1911/1983), while later concluded that large companies, through their in-house R&D laboratories, would assume an even more important role compared to new and smaller firms (Schumpeter, 1942/2014).

Building on these ideas, a number of studies have focused on analyzing the two basic patterns of innovation highlighted by Schumpeter, namely Mark I and Mark II (Malerba and Orsenigo, 1996; Breschi et al., 2000). Schumpeter Mark I is a turbulent environment characterized by the "creative destruction" of established technologies and business practices. In this context, innovations are mainly generated by new innovative firms, which finally end-up to replace incumbents: "new entrepreneurs come in an industry with new ideas and innovations, launch new enterprises which challenge established firms and continuously disrupt the current ways of production, organization and distribution" (Breschi et al., 2000). Schumpeter Mark II is instead a stable environment characterized by the "creative accumulation" of existing technologies, capabilities and resources. Here, the main players are large established firms, which benefit from the consolidation of their accumulated knowledge, creating high entry barriers to new firms. In brief, Mark I is characterized by the emergence of disruptive innovations, the entry of new innovators and the erosion of the competitive and technological advantage of the established firms, while Mark II is associated with more incremental or sustaining innovations and the dominance of established firms. According to these studies, the observed patterns of innovative activities within a sector largely depend on the specific characteristics of involved technologies, including technological opportunities, appropriability of innovations and cumulativeness of technical advances (Malerba and Orsenigo, 1996). Early in the history of an industry or in the presence of major technological and market discontinuities, Mark I will tend to prevail because in those circumstances technological opportunities are high, while appropriability and cumulativeness are low (Malerba, 2002). Therefore, barriers to entry are low. On the contrary, when the industry matures and technological change follows well defined trajectories, economies of scale, learning curves, barriers to entry and financial resources become important (Malerba, 2002). More recently, Fontana et al. (2012) have showed that breakthrough inventions are more likely to emerge in "turbulent" Schumpeter Mark I type of contexts.

The challenges of incumbent firms in face of radical innovation are also analyzed by the technological discontinuities approach (Tushman and Anderson, 1986; Anderson and Tushman, 1990) and the disruptive innovation approach (Christensen and Rosenbloom, 1995; Christensen, 1997). According to the first approach, technology evolves through long periods of incremental change punctuated by technological discontinuities, which can be either competence-destroying or competence-enhancing. Competence-destroying discontinuities require fundamentally new skills and know-how to be generated and focus on developing new products that eventually replace existing ones. On the contrary, competence-enhancing discontinuities build on existing skills and know-how, focusing on revitalizing existing products with complementary technologies. Both discontinuities introduce variation in a product class, triggering a period of technological ferment characterized by experimentation, competition among technological variants and