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Sectoral patterns versus firm-level heterogeneity - The dynamics of eco-innovation strategies in the automotive sector

Lourenço Galvão Diniz Faria *, Maj Munch Andersen

Technical University of Denmark, Department of Management Engineering, Diplomvej 372, 2800 Kgs. Lyngby, Denmark

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ABSTRACT

This paper sheds light on some important but underestimated elements of green industrial dynamics: the evolution of firms' eco-innovation strategies and activities within a sector. While eco-innovation sectoral case studies have taken place before, our analysis is distinct in investigating the rate, direction and extent of eco-innovation in the automotive sector, represented here by the main automakers, in order to identify possibly sectoral-specific patterns in firms' strategies, as opposed to divergent strategic behaviors, grounded on evolutionary economic theory. We conduct a two-step empirical analysis using patent data from 1965 to 2012. Our findings suggest a process of co-evolution of firms' strategies and indicate that strong sectoral-specific patterns of eco-innovation are present in this sector from the mid-2000s onwards. For fuel cells technologies, however, we observe the formation of two antagonist patterns. A further econometric analysis is conducted and indicates that the positioning of the firms between these two groups is correlated with the firms' profit margins and the size of firms' patent portfolios.

1. Introduction

The remarkable rise of the green economy as a new techno-economic paradigm (Freeman, 1996) and the role of eco-innovations as mechanisms to reach higher levels of both economic and environmental development have been object of little attention by evolutionary innovation scholars. Furthermore, the focus of the relatively few studies in this field has been mainly on the role of policy mechanisms in influencing eco-innovation e.g. (Hojnik and Ruzzier, 2015; Kemp and Oltra, 2011), rather than the understanding of the green industrial dynamics itself (Andersen and Faria, 2015).

This paper seeks to contribute to the latter combining some of the core assumptions of firm theory at micro-level with meso-level evolutionary frameworks (Nelson, 1991). The basic idea is that firm's technological strategies at micro-level accumulate and ultimately shape the technological development at the sector level. Evolutionary researchers have argued that firms in the same sector could be subject to some convergence in their innovation strategies, forming sector-specific technological trajectories (e.g. Pavitt, 1984; Breschi and Malerba, 1996; Klevorick et al., 1995; Malerba, 2002). While this is a recognized argument in evolutionary research, it is also been contested as evolutionary theories also highlight firm heterogeneity and hence the key importance of firms' technological strategies (Patel and Pavitt, 1997; Peneder, 2010).

As a first step towards understanding this complex theme, this paper aims to undertake a case study of the automotive sector. We aim to analyze the rate, direction and extent of the greening of the automotive sector, highlighting the firm-level dynamics and the green technological strategizing, over the last decades. Using patent data, the paper analyses eco-innovation activities in the automotive sector from 1967 to 2012, i.e. the main period of industrial greening. The eco-innovations considered are restricted to the core automotive innovation, the powertrain. This is partly to delimit the quite comprehensive analysis, partly to allow for a focus on comparing the greening of the mature dominant design, the combustion engine versus the upcoming competing green trajectories (related to respectively hybrid/electric and fuel cell based cars).

In mature markets, firms with better dotation of internal resources or specific combinations of external developing new technologies compared to firms that face inadequate conditions (Abernathy and Clark, 1985). On the other hand, firms' strategies are also influenced by, for instance, country and technology specific elements (Malerba and Orsenigo, 1996). The greening of the automotive sector is characterized by the existence of competing technologies at different development stages and with distinct degrees of differentiation from the dominant design, and therefore the decision to invest in one or more of these technologies might at any given time be more or less influenced by firms' internal versus external characteristics (Wesseling et al., 2015).

* Corresponding author.
E-mail addresses: loufa@dtu.dk (L.G.D. Faria), mmua@dtu.dk (M.M. Andersen).

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Some studies analyze changes in green technological strategies of individual firms in the automotive industry. While some highlight the increase in technological variety due to the greening of the sector (e.g. Frenken et al., 2004; Oltra and Saint-Jean, 2009b), others defend that some firms are developing specific green technologies (Pohl and Yarime, 2012; Sierzchula et al., 2012). Many cite successive shifts in firms' strategies between fuel cells, battery electric and hybrid electric technologies during the past 20 years (Konrad et al., 2012; van den Hoed, 2007). Overall, the evidence on the dynamics of eco-innovation in the sector and the factors affecting firms' decision vary somewhat. None of these studies, however, address the research question we ask here: How homogenous is the greening process over time in this sector?

In a previous related paper we focused more on the meso-level dynamics of eco-innovation in the sector (Faria and Andersen, 2015). In this paper, we found a strong reduction in the concentration of green patenting activity within the automotive sector for some core technologies, namely Advanced Internal Combustion Engines (ICE), Hybrid/Electric Engines, and Complex patents[1] in the past decades. However, a fourth group, *fuel cells*, remained relatively more concentrated in few firms. In this paper we seek to expand on these findings, with a particular emphasis on investigating how the aggregate reduction in patenting concentration is reflected in the firm-level data, and why the fuel cell case differ from the others.

To some degree this paper represents a narrow perspective on innovation. The analysis has due to space limitations been restricted to the automotive sector only while excluding suppliers. Nevertheless, we argue that the degree of sectoral greening can be analyzed at the sector level only, presuming that the role of suppliers is likely to be distributed across the sector. The focus of the paper is strictly on patenting activities, which excludes to a high degree an analysis of the institutional setting and its changes over time in the period analyzed. We argue that these delimitations are necessary in order to carry out a comprehensive, detailed analyzed of the eco-innovative activities within the sector, and that in fact they open room for future complementary research that includes other actors and compare different data sources.

Overall, our findings suggest a process of co-evolution of firms' strategies within the sector and indicate that sectoral-specific regularities in the eco-innovation patterns are increasingly present in this sector, adding up to the still incipient literature on the existence of sectoral patterns of eco-innovation (e.g. Andersen and Faria, 2015; Mazzanti and Zoboli, 2006; Oltra and Saint-Jean, 2009a). For fuel cells technologies, however, we observe the formation of two opposite patterns, and our statistical analysis indicates that the positioning of the firms between these two groups was significantly correlated with the firms' profit margins and the size of patent portfolio.

The paper is organized as follows: in Section 2, we conduct a critical literature review on the determinants of changes in firms' technological strategies for innovation and eco-innovation, and discuss the greening of the automotive sector in perspective. Section 3 presents the data preparation and methodological steps for the descriptive and econometric procedures. Section 4 presents the results of both analyses and Section 5 concludes.

2. Literature review

2.1. Determinants of changes in firms' technological strategies

As Faber and Frenken (2009) argue, the strength of the evolutionary perspective "(…) lies in its strong microeconomic foundations. It builds on behavioral theory of the firm and provides a more realistic description of the technological black box" (p. 467). Differences in firm behavior and characteristics have a crucial role in explaining innovation dynamics and the study of the innovation dynamics at the macro and *meso* levels must include an understanding of which factors influence changes in firms' *technological strategies*, as these factors reflect the creation and selection mechanisms (Nelson, 1991).

A technological strategy can be understood as continuous alignments between firms' internal capabilities/competencies and external conditions in unique arrangements in order to generate and sustain competitive advantages (Porter, 1996). In this sense, organizations operating in lean environments tend to develop a short-term mentality and avoid technological experimentation (Aldrich, 1979; Rothenberg and Zyglidopoulos, 2003), directing innovative search to the neighborhood of the established technologies in order to exploit existing firm-specific assets and competences and avoid potential risks, often generating core-rigidities[2] (Dosi, 1988), unless sufficient opportunities arise and outshine such inertial forces, so that firms change their strategies towards new trajectories (Perez, 2009).

In lean and mature markets, firms with better dotation of internal resources[3] and/or healthier financial records – and therefore greater flexibility – may perceive smaller risks of developing new technologies compared to struggling firms that face scarce or inadequate internal resources to bet and bigger obstacles to obtain external funding for their R&D activities (Barney, 1991; Cainelli et al., 2006; Patel and Pavitt, 1997). Moreover, external elements – including the characteristics of regulatory, competitive and scientific/technological environments, can generate both incentives or obstacles to change (Perez, 2009; Porter and Van der Linde, 1995). General economic conditions, reputation scandals and crises may also exert important influences in firms' willingness to change technological strategies (Archibugi et al., 2013; Paunov, 2012).

Since firms in the same sector or region often share internal characteristics and are subject to similar external conditions (i.e. regulations, competition), collective perceptions about technologies' risks and opportunities might arise, originating sector- (Klevorick et al., 1995; Malerba, 2002; Pavitt, 1984) or geographic-specific patterns of innovation (Cooke et al., 1997; Lundvall, 1992). On the other hand, distinct patterns may arise in the same sector or country due to firm heterogeneity, i.e. differences in internal resources or bounded rationality (Dosi, 1997; Leiponen and Drejer, 2007; Peneder, 2010).

Observable changes in technological strategies can be considered indicators of perceived opportunities from new technologies. Observing the (in)existence of patterns of change in firms technological strategies improves our understanding of which dimensions stand out, influencing the innovative change (Patel and Pavitt, 1997). Considering the green innovative dynamics, Cainelli et al. (2015) argues that firms' internal and external characteristics play a crucial role to understand eco-innovation's development due to its higher complexity (in terms of novelty, uncertainty and variety) when compared with established technologies.

Among the eco-innovation literature, however, scholars have been mainly focusing on the role of institutional mechanisms such as environmental policy instruments in influencing firms' green technological strategies, given the specific challenges and barriers that the market forces face in the greening process such as the "double externality problem" (Johnstone et al., 2010; Porter and Van der Linde, 1995; Rennings, 2000; van den Hoed, 2007). Despite the substantial contribution to the understanding of aggregated, general

[1] See Section 3 for a description of this group.

[2] Numerous studies point out that this inertia may promote the entrance of new firms that perceive smaller risks due to their absence of organizational and technological inertial forces (Abernathy and Utterback, 1978; Anderson and Tushman, 1990).

[3] By *internal resources* we mean all resources firms possess to undertake their innovative activities including, for example, their capabilities, R&D structure, organizational routines, tacit knowledge, alliances and networks (Barney, 1991).