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Non-disruptive regime changes—The case of competing energy efficient lighting trajectories

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ABSTRACT

Technologies within the same industry are expected to follow similar patterns of innovation, and when the dominant patterns change, this is often expected to have disruptive effects on the industry. However, the three most recent lighting technologies (fluorescent, compact fluorescent, and LED) show different patterns of innovative activities despite similarities in the determinants of innovation; and we observed multiple technological regimes within the lighting industry. Furthermore, we observed changes in these innovative patterns without widespread disruptive effects. While FL and LED quickly improved once they were introduced, CFL struggled for decades. We present an historical case study of the emergence and development of the different regimes and we present possible explanations to be found in market structure and selection criteria. The analysis shows the important role for policymakers in stimulating new technologies in industries with undesirable Mark II pattern through the influence of all the dimensions of the technological regimes.
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1. Introduction

Policy makers are increasingly interested in new eco-efficient lighting technologies to decrease energy consumption, reduce energy costs, and create new business opportunities (European Commission, 2011). In the previous century, the fluorescent light (FL) and its residential application, the compact fluorescent light (CFL), were considered the most promising future lighting technologies, but today attention is shifting towards light emitting diode (LED) technology (Chappin and Afman, 2013). In order to adequately support the development and diffusion of eco-friendly technologies, insight into their specific innovation trajectories is necessary (Alkemade et al., 2011; Quitzow et al., 2014). This insight is especially needed in the case of alternative lighting technologies because their development seems to deviate from the patterns predicted by theory.

More specifically, the literature describes how technologies within an industry usually develop under the same *technological regime* (Nelson and Winter, 1982), and display similar sectoral patterns of innovative activities (Breschi et al., 2000; Pavitt, 1984; Malerba and Orsenigo, 1993, 1996). These similarities arise because the main determinants of innovation, such as technological opportunities, the appropriation of innovations, the cumulativeness of technological advances, and the properties of the knowledge base, are similar for all firms within an industry (Malerba, 2002). In addition, theory predicts

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that changes in these patterns arise mainly as a result of major (technological) discontinuities that disrupt the industry. As we demonstrate in this paper, the three alternative lighting technologies, FL, CFL, and LED, are characterized by different patterns of innovative activities despite similarities in the determinants of innovation; and we observed multiple technological regimes within the lighting industry. Furthermore, we observed changes in these innovative patterns without widespread disruptive effects on the industry.

The three alternative lighting technologies have many common characteristics as they were developed through long-term intensive R&D processes in an oligopolistic context in which General Electric (GE) played a leading role, especially during the R&D phase. The similarities among FL, CFL, and LED suggest that these technologies developed within the same or a similar technological learning regime, and we would therefore expect similar patterns of innovative activity (Malerba and Orsenigo, 1997; Pavitt, 1984). However, once introduced to the market, FL and LED quickly improved through learning and became dominant, while CFL experienced slow progress and struggled for decades. Observing these differences between expected and actual patterns of diffusion, led to our main research question: *How can we explain the observed differences in the innovative patterns of FL, CFL, and LED despite similarities in the main determinants of innovation for these technologies?*

The paper is organized as follows: Section 2 describes the theoretical framework, and Section 3 gives a brief description of the methodology. Section 4 presents the history of the alternative lighting technologies. Section 5 discusses the different technological regimes, and Section 6 provides conclusions.

2. Innovation dynamics and profit-driven industry evolution

Profit is the main driver of a firm's innovative efforts (Jacobides and Winter, 2007). Schumpeter pointed out that firms develop both short-term and long-term profit strategies to seize the value of innovation, commonly defined as a new combination of elements with a final value superior to the sum of the value of the individual elements (Schumpeter, 1934). Short-term profit strategies aim to seize current profits in the market through decisions about price and quantity (Jacobides et al., 2006), and thus focus on protecting the firm's current products and market share (Teece, 1986). Long-term profit strategies focus on the generation of novelties in a context of uncertainty (Langlois, 2007) and the creation of new profit flows. This strategy corresponds to the well-known Schumpeterian concept of creative destruction that refers to an innovations' disruptive effect on profit flows (Cantwell, 2000; Lundvall et al., 2002).

In order to develop its portfolio of short- and long-term strategies, a firm considers both the potential value of a future innovation, the actual chance of capturing this value, and the innovation's impact on current profit flows. This relation between short-, and long-term strategies leads to a strategic dilemma for the firm: on the one hand, a consistent flow of short-term profits is necessary to generate resources to sustain long-term strategies, but on the other hand, new innovations may negatively affect short-term profits, causing firms to shy away from developing them. Since firms have heterogeneous capabilities developed through cumulative patterns (Cantwell, 2000; Jacobides et al., 2012; Mowery, 2010), they develop complex, individual, and time-dependent (Jakopin and Klein, 2012) innovation strategies.

Schumpeter captured this complexity of innovation activities in different markets in two stereotypic market models, often labeled as Mark I and Mark II (Breschi et al., 2000). The Mark I model highlights the role of newcomers who develop innovations that disrupt the incumbents' short-term profits (Chandy et al., 2000). As soon as these newcomers stabilize the novelties they have brought to the market, they focus on short-term profits and become the new incumbents, creating space for other future newcomers (Andersen, 2012). Management literature, and previous case studies, have identified the pivotal role of entrepreneurs in this process (Schumpeter, 1934; Venkataraman, 1997; Tilley and Parrish, 2009; Hockerts and Wüstenhagen, 2010; Hekkert et al., 2007; Markard and Truffer, 2008). Incumbents are often regarded as playing a more defensive role in sustainability transitions. Garud (1994) describes how incumbents often reject new technologies "because of the strength and inertia built into their existing technological". The competences of incumbent firms developed within this existing technological paradigm are geared towards the old technology (Penrose, 2016; Christensen, 1997; Anderson and Tushman, 1990). Furthermore the small niche markets that help to shape the new technology are often not financially attractive to large firms (Christensen, 1997). However there also exists empirical evidence of incumbent firms that are able to adequately adapt to radical technological change and competence-destroying innovations (Arend, 1999; Hill and Rothaermel, 2003; Afuah, 2001).

The Mark II model highlights the role of stable oligopolistic incumbents as main innovative players (Mowery, 2010). In this mode incumbents are dominant because they can exploit short-term profits and thus sustain new innovative efforts. Hence, market power is a means and not the reason for incumbents' dominance and in both models the locus of competitiveness is innovative capacity. Recent literature has proposed combining Mark I and Mark II patterns into new market models in which technological evolution is depicted through the interaction of small and big players who mutually benefit from their different capabilities (Andersen, 2011).

The literature about the determinants of innovation and technological regimes has further specified the Schumpeterian innovative patterns (Malerba and Orsenigo, 1997), thereby connecting the Schumpeterian patterns of innovation to the knowledge-base characteristics that occur at the sectorial level. A technological regime is defined as the combination of four determinants: opportunity—how easy it is to innovate—, appropriability—the possibility of extracting profits from innovation—, cumulativeness of knowledge—the extent to which new knowledge builds on earlier knowledge—, and the knowledge base—the nature and means of knowledge—, and their combinations define the different Schumpeterian patterns. The determinants of innovation have been used to explain the different Schumpeterian patterns of innovation (Cohen and

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