Research Policy 42 (2013) 1469–1481

Contents lists available at SciVerse ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

The era of incremental change in the technology innovation life cycle: An analysis of the automotive emission control industry

Jaegul Lee[a,*], Nicholas Berente[b,1]

[a] School of Business Administration, Wayne State University, 5201 Cass Avenue, Detroit, MI 48202, United States
[b] Terry College of Business, University of Georgia, Athens, GA, United States

ARTICLE INFO

Article history:
Received 8 September 2011
Received in revised form 19 March 2013
Accepted 6 May 2013
Available online 12 June 2013

Keywords:
Dominant design
Era of incremental change
Technology life cycle
Core components
Automotive emission control systems

ABSTRACT

According to the life cycle model of technological evolution, after the emergence of a dominant design, technological product industries undergo an "era of incremental change." This era of incremental change is not well understood in the existing literature. Although the period is typically characterized in terms of stability and minimal innovation, we find that the era of incremental change can be actually quite dynamic. Through our research into the period of time following the emergence of a dominant design in automotive emission control systems, we find that the overall product innovation in the industry did not decline immediately following the dominant design, and increased throughout the era of incremental change. Further, we find that firms maintain their attention on the same core components that they innovated upon before the dominant design, but that these components make up less of the overall proportion of total innovation throughout the era of incremental change. Finally, we found that the concentration of innovating firms in the industry increases immediately following the dominant design, and this concentration decreases over time throughout the era of incremental change. Findings imply a pattern of contraction and expansion in the era of incremental change that extends previous work on the technological product life cycles and helps to characterize the era of incremental change in a novel way.

1. Introduction

The early stages of new technological products are marked by periods of intense innovation and competition among contending product concepts until one emerges as the "dominant design" in an industry (Anderson and Tushman, 1990). After a dominant design emerges, there is a period of relative stability that has been characterized as the "era of incremental change" (Anderson and Tushman, 1990). During this era of incremental change, the product architecture remains stable and firms transfer their attention from the overall product to innovation associated with manufacturing processes, cost reductions, component improvements, and customer segmentation (Abernathy and Utterback, 1978; Anderson and Tushman, 1990; Henderson and Clark, 1990; Funk, 2003). The era of incremental change is marked by organizational, social, and political stabilization (Tushman and Rosenkopf, 1992) that stands in stark contrast to the innovative turmoil and intense standards battles that precede the dominant design (Suarez, 2004). Essentially, the *level of technological innovation* diminishes as firms focus on other areas of improvement (process, customer segmentation, etc.); the *type of technological innovation* shifts to lower (and presumably less impactful) component levels; and the *concentration of firms* doing the innovating increases and stabilizes (Anderson and Tushman, 1990; Tushman and Rosenkopf, 1992; Murmann and Frenken, 2006). What happens after a dominant design emerges is often seen as theoretically "uninteresting" by researchers (Dokko et al., 2012, p. 682) – at least until the next technological disruption.

Recent research has found, however, that this neglected period in technological life cycles can be quite interesting – and is not as stable and incremental as was previously thought (Murmann and Frenken, 2006; Funk, 2009; Dokko et al., 2012). Take, for example, the case of the catalytic converter in automotive emission systems. In the 1970s there was an intense battle between competing standards intended to reduce pollutants from cars and fit regulatory emissions standards. Two different physical designs (dual converter and three-way) and two types of catalysts (pelleted and monolithic) were vying for the standard until the market settled on the on monolithic three-way converter architecture that has been standard for more than thirty years (Mondt, 2000; Heck and Farrauto, 2002). Automotive emissions stabilized on a dominant design in 1981, and in the first twenty years after this dominant design emerged, patenting activity associated with emissions increased significantly, overall performance of emissions technologies improved by a factor of three, and the digital revolution was

* Corresponding author. Tel.: +1 313 577 4565; fax: +1 313 577 5486.
E-mail addresses: jaegul.lee@wayne.edu, jaegull@gmail.com (J. Lee), berente@uga.edu (N. Berente).
[1] Tel.: +1 706 542 3587; fax: +1 706 583 0037.

0048-7333/$ – see front matter
http://dx.doi.org/10.1016/j.respol.2013.05.004

leveraged to enable unprecedented emissions control and tuning (King and Lyytinen, 2005; Lee et al., 2011; Lee and Berente, 2012). This level of innovation can hardly be ignored by researchers of technology innovation, and causes us to question whether the technological innovativeness of the era of incremental change is, in fact, necessarily less than the time preceding the emergence of the dominant design (as posited by Anderson and Tushman, 1990). Also, with the focus on other innovations and improvements, does the low level of technological innovation (associated with products after a dominant design) necessarily remain stable throughout the era of incremental change? Further, given that organizational, social, and political dynamics may not stabilize in the same way that they are often characterized in the era of incremental change (Dokko et al., 2012), might the concentration of firms innovating in an industry be in greater flux than previously thought?

To address these questions and thus contribute to the literature on evolutionary lifecycles of technologies, we studied the period of time associated with the emergence of a dominant design in automotive emission control systems. We analyze patent data for the period from 1970 to 1994 and compare pre and post dominant design patterns of activity. These comparisons include: (1) the overall *level of technological innovation*; (2) the relative proportion of different *types of component innovations*; and (3) the overall *concentration of firms* innovating in the industry. We find that, contrary to some of the previous literature, that the overall rate of product innovation does not decrease immediately following the dominant design – and it appears to increase throughout the era of incremental change rather than stabilize or diminish. Also, firms do not immediately shift their innovative attentions away from "core" components where they focused before the dominant design. However, the overall proportion of innovation comprised by these core components does decrease over the era of incremental change. Finally, consistent with much of the literature, we find that the concentration of innovating firms increases immediately following the emergence of a dominant design, but decreases over the era of incremental change.

The remainder of the paper is organized as follows. First we briefly review the literature on the product life cycle model of technological innovation, followed by the development of our hypotheses about the nature of innovation in the era of incremental change. We then present our research into automotive emissions control systems, and conclude with a discussion of our findings.

2. Dominant designs and the era of incremental change

The product life cycle model of technological innovation (e.g. Anderson and Tushman, 1990; Utterback and Suarez, 1993) is the leading framework for research into the dynamics of product evolution over time (Murmann and Frenken, 2006). According to this view, in the evolution of technological products, there is an intense period of "ferment" whereby firms compete for dominance with their versions of new product concepts, which culminates in the emergence of a dominant design. A dominant design is a stabilized "operational principle," or product architecture, that gains a majority of the market (Murmann and Frenken, 2006). Once a dominant design emerges, there is a calm period of relative stability and incremental innovation until the next disruption. The calm period, which is referred to as the "era of incremental change" (Anderson and Tushman, 1990) has traditionally received relatively little scholarly attention.

The era of incremental change is marked by a shift from product to process innovation (Abernathy and Utterback, 1978), accompanied by a general reduction of innovativeness and a focus on cost reduction and minor component and subsystem innovation (Anderson and Tushman, 1990). These efforts can be combined with product customization for differentiated market segments and other forms of detailed, "lower level" problem solving (Funk, 2003). Organizational, social, and political forces stabilize around a particular product architecture (Tushman and Rosenkopf, 1992), and firms narrow their attention to more intensely address the component technologies associated with dominant design (as opposed to innovating on the architecture, see Henderson and Clark, 1990). Because the era of incremental change is generally thought to deal with minor changes and fairly stable phenomena, the bulk of research into the technology life cycles has historically focused on technological (architectural) discontinuities and the battles for dominant design (Suarez, 2004), and often ignores the era of incremental change.

Recent work, however, has found that the era of incremental innovation is not quite so stable and uninteresting as it was (perhaps) previously thought. Incremental component innovations are often the source of the discontinuities in product architectures that result in disruptive innovations (Funk, 2009). Social and political elements of industries continue to be in a state of flux throughout the era of incremental innovation (Dokko et al., 2012). Many industries – particularly digitally intensive industries – do not exhibit the stability (associated with inverted "U" shaped innovation cycles) that life cycle theory implies (Murmann and Frenken, 2006). Further, firms with products associated with a dominant design do not necessarily reduce the scope of their technology innovation efforts – many maintain capabilities and continue to innovate across product levels and relevant components (Brusoni et al., 2001).

Although the era of incremental change may not be so stable and "uninteresting" (Dokko et al., 2012), there are some points upon which the literature broadly agrees. For example, when a dominant design emerges for a given product, uncertainty is reduced with respect to product architectures (the operational concepts and linkages between components) and firms do shift their attention from architectures to different innovations associated with the product (Murmann and Frenken, 2006). Some of this attention will focus on product innovation at a component[2] level (Henderson and Clark, 1990), but innovative activities following the dominant design will also focus elsewhere – such as on manufacturing processes. This means that the overall product innovation in this period of time will be significantly less than in the era before the dominant design, and the rate of such innovations will likewise diminish or remain minimal as this attention is spread across these different objectives (Anderson and Tushman, 1990). Further, market dynamics among firms will stabilize and solidify around shared routines, which would limit the number of new entrants (Tushman and Rosenkopf, 1992; Murmann and Frenken, 2006).

Thus we have three dimensions along which we can expect a difference between the era of ferment and the era of incremental change: the level of product innovation, the type of product (component) innovations, and the industry composition (i.e., concentration of firms). Next we will briefly attend to each dimension, followed by hypotheses derived from the extant literature.

2.1. Level of product innovation

According to the traditional view, "most of the total performance improvement over the lifetime of a technology will occur outside the era of incremental improvement" (Anderson and Tushman, 1990, p. 618). After the dominant design emerges, there is a "period of inertia" characterized by network externalities, lock in, and standard interpretive frames that limit product innovations to the types

[2] For simplicity, in this paper we use the term "component" as a generic term for any of the nested subsystems within a technological product hierarchy (Murmann and Frenken, 2006).