Dominant Designs, New Firm Survival and Competitive Dynamics in Nascent Market Categories

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ABSTRACT

Dominant Designs, New Firm Survival and Competitive Dynamics in Nascent Market Categories
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Technological change represents a key driver to shape new market categories and organizations. Characterized by a process of social technological variation, selection and retention, the growth of a nascent market category manifests changing competitive dynamics and the success (or failure) of entrepreneurial organizations, particularly in the face of dominant designs — technologies that achieve absolute dominance in specific market categories. In spite of accumulated research on dominant designs in diverse perspectives (e.g., economics, marketing and strategic management), the understanding of this dynamic process is yet incomplete. Building upon the punctuated equilibrium model of technological change, I address several research questions in regard to the interface between technological evolution, dominant designs, competitive dynamics, and institutional entrepreneurship. I conduct three separate yet interconnected studies in search of conceptual links among these areas of research.

The first essay organizes the diverse but fragmented management literature on dominant designs based on the meta-theoretical scheme developed by Astley and Van de Ven (1983). The essay systematically reviews and assesses the "central perspective(s)" of over 89 relevant papers in influential journals in management, marketing and management related disciplines. Cumulative research streams on this topic have stayed within a single central perspective, the development of research across the four central perspectives has been uneven, and works incorporating multiple central perspectives have

been limited in number. The essay argues for complex models that take into account the two boundary conditions — technological complexity and institutional environment — which have been implicit in the extant literature. The essay calls for more theoretically grounded works in collective action and strategic choice views, but the major opportunity lies in integrative works that will take this research one step closer to a comprehensive view of dominant designs.

In the second essay, I posit a conceptual link between the punctuated equilibrium model of technology change and dynamics of entrepreneurship. I develop hypotheses addressing the relationships between competitive environment (including competitors), firm strategy (resources) and survival of entrepreneurial firms seeking the establishment of dominant designs. This effort to investigate the edge between technological change and entrepreneurship improves our understanding of the opportunities and threats facing new organizations in the technological field, as well as the strategies that innovative new ventures may deploy to enhance survival chance in turbulent industries.

The third essay adds insights to the sustained work on the process models of dominant designs by empirically examining the association between technological evolution and competitive dynamics to define dominant designs. This essay discusses how the frequency and complexity of firms' competitive actions surrounding dominant designs co-evolve along the life cycle of technological discontinuities. I examine the influence of three factors: the *stage* of the technological regime, the *density* in the market category, and the *emergence of dominant designs* in the market category. I found these factors strongly influence on firms' competitive actions both directly and through interactions with related factors.

CHAPTER ONE: INTRODUCTION

Strategic management research has observed a growing interest in competitive dynamics associated with technological change and the emergence of dominant designs or de facto standards (Clymer & Asaba, 2008; Gallagher, 2007; Schilling, 2002; Soh, 2009; Srinivasan, Lilien, & Rangaswamy, 2006; Suarez, 2004). Representing a major technical advance that offers sharp improvements over existing technologies (Dosi, 1982; McGrath, Macmillan, & Tushman, 1992; Sahal, 1981; Shapiro & Varian, 1999b; Tushman & Anderson, 1986), a technological discontinuity introduces an "era of ferment" in which technological variants compete and compromise to define a dominant design – a single technology that accomplishes dominance in a product class (Abernathy & Utterback, 1978; Anderson, Jack, & Dodd, 2005; Anderson & Tushman, 1990; Benner & Tushman, 2003; Soh, 2009). Since a dominant design serves as a technological base, or a *platform*, that allows other technologies to be developed (Cusumano & Gawer, 2002; Gandal, 1994; Jones, 2003; Schilling, 2000), firms controlling dominant designs are de facto technological leaders who decide the "rules of engagement" of relevant socio-technological spaces (Garud, Jain, & Kumaraswamy, 2002). In spite of cumulative research on dominant designs in diverse perspectives (e.g., economics, marketing and strategic management), the understanding of this dynamic process is yet incomplete. In this dissertation, I address several research questions in regard to the interface between technological evolution, dominant designs, competitive dynamics, and institutional entrepreneurship. I conduct three separate yet interconnected studies in search of conceptual links among these areas of research.

Essay One: Research on Technology Standards

The first essay organizes the diverse but fragmented management literature on dominant designs based on the meta-theoretical scheme developed by Astley and Van de Ven (1983). The essay systematically reviews and assesses the "central perspective(s)" of over 89 relevant papers in influential journals in management, marketing, and management related disciplines. An integrative review of existing literature will facilitate conversations among research streams. The review will bridge works under different labels clarifying connections among them, organize the literature within a relevant framework summarizing the linkages and differences among levels of analysis, identify significant gaps in knowledge and distill opportunities for integration. Such a review will also allow standards scholars of different theoretical stances to reconcile contrasting theories and bring together dialectical interpretations of various facets of the phenomenon (Astley & Van de Ven, 1983).

To achieve theoretical integration, I utilize Astley and Van de Ven's (Astley & Van de Ven, 1983) influential framework for organizing management theories to distinguish various strands of work in this domain. Astley and Van de Ven's framework is uniquely suited for this purpose because their scheme accommodates a) macro and micro levels of analysis, b) environmental selection, firm adaptation and strategic choice, and c) individual and collective actions of firms – all of which are not only relevant to the phenomenon of standards but have been the factors along which the literature has developed leading to the current state of fragmentation.

Essay Two: Dominant Designs and New Firm Survival

In the second essay, I posit a conceptual link between technology change and survival of new firms seeking institutional entrepreneurship in turbulent technological environments. Research has shown that every firm faces challenges as a new venture at one point and its success in the early corporate lineage depends substantially on its ability to develop the *fit* between its strategy and the industry in which it competes (Fan, 2010; Geroski, Mata, & Portugal, 2010). In the attempt at understanding these dynamics, scholars incorporated various academic perspectives to theorize the linkages between new firms' competitive environment, strategy and performance (Fan, 2010; Hannan & Freeman, 1988; Romanelli, 1989). One research stream has particularly focused on the success of new firms in the course of technological evolution (Kim & Kogut, 1996; Zahra, 1996; Zahra & Bogner, 2000). Scholars suggested that firm performance in the technology industry is a function of the firm's response to technology change, particularly, in the process in which the dominance of a single technology or design is established in a product class (Christensen, Suarez, & Utterback, 1998; Mitchell, 1991; Soh, 2010; Suarez & Utterback, 1995; Tegarden, Hatfield, & Echols, 1999; Tushman & Anderson, 1986).

Such a dominant technology, or a de facto standard, represents the industry-wide agreed-upon technical logic for product design and interconnectivity (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Soh, 2010). While the emergence of a de facto standard rests in the form of technical design, the impact of such an event is not merely a technological issue. Researchers have pointed out that the establishment of a de facto standard defines key facets of emerging social-economic institutions, whereby the winning design dictates ‘rules of engagement’ and collective benefits of various economic agents (Garud et al., 2002; Garud & Kumaraswamy, 1993; Hargadon & Douglas, 2001). In effect, once a de facto standard begins to emerge, it not only gains mass adoption in the technological community based on its design, but also tends to lock out all other technological communities pursuing alternative designs, leading to a situation known as winner-take-all (Anderson & Tushman, 1990; Arthur, 1989; Schilling, 2002; Suarez, 2004). However, due to technological variation and competition, the emergence of a de facto standard is a highly uncertain process (Anderson & Tushman, 1990; Christensen et al., 1998; Suarez & Utterback, 1995; Tegarden et al., 1999). Accordingly, the firm’s involvement in standard-based competition represents both an important opportunity to establish its core competence and destroy that of competitors, and a substantial risk of being technologically locked out if the design the firm sponsors turns out not able to accomplish technological dominance (Anderson & Tushman, 1990; Schilling, 2002).

To date, the focal point of empirical studies on firms’ engagement in standard-based competition has been on firms’ adaptation in the face of de facto standards (e.g. Christensen et al., 1998; Suarez & Utterback, 1995). But firms’ strategy in this competition is not merely a matter of adaptation. Several researchers suggested that firms with technical capabilities to create original designs are often strongly committed to establishing de facto standards (Cusumano & Gawer, 2002; Garud et al., 2002; Khazam & Mowery, 1994; Suarez, 2004; Wade, 1996; Waguespack & Fleming, 2009). In the innovation literature, these firms are referred to alternatively under such labels as ‘institutional entrepreneurs’ (Garud et al., 2002; Hargadon & Douglas, 2001; Maguire, Hardy, & Lawrence, 2004) or ‘platform leaders’ (Adner & Kapoor, 2009; Cusumano & Gawer, 2002).

Creating de facto standards is a particularly meaningful strategy for new ventures whose success depends on the ability to launch ‘creative destruction’ (Schumpeter, 1934a, 1950) — by initiating technology change and thus new standards, new firms can not only destroy the competence of established competitors but also become a new generation of de facto industrial leaders (e.g., Microsoft and Adobe Systems). Yet this standard-based entrepreneurship is a risky business (Hargadon & Douglas, 2001). In particular, cases such as Lotus Development and Netscape indicate that even for firms who have accomplished technological dominance at one point of time, the risk factors from the technological field or poorly designed competitive strategy may completely dethrone their leadership, forcing these once glorious organizations to exit from the market. These observations lead to the research question: How will technological evolution and firm strategy influence the likelihood to exit of de novo ventures that compete by creating original designs? In the effort to provide an answer to this unaddressed issue, I draw from various theories and develop five hypotheses to conceptualize the links between the competitive environment, competitive actions and the likelihood to exit of design-based entrepreneurial ventures. I find strong empirical support for the theoretical framework based on panel data of 188 design-based entrepreneurial ventures in the period from 1980 through 2006.

Essay Three: Technological Change, Dominant Designs and Competitive Dynamics

The third essay adds insights to the sustained work on the process models of dominant designs by empirically examining the association between technological evolution and competitive dynamics to define dominant designs. This essay discusses how the frequency and complexity of firms' competitive actions surrounding dominant designs co-evolve along the life cycle of technological discontinuities. Indeed, the impact of technological change on industry and organizations has attracted substantial attention among theorists of innovation and strategy. A fruitful research stream has conceptualized technological change as an evolutionary process of technological variation, selection and retention (Anderson & Tushman, 1990). Technological discontinuities introduce variation into otherwise stable technological fields by creating new technological trajectories and markets, followed by a selection process in which social, political and economic forces as well as entrepreneurship initiate competitive dynamics to determine a *standard* or a *dominant design* among various technological variants in the nascent market category (Anderson & Tushman, 1990; Garud, Gehman, & Karnoe, 2010; Hargadon & Douglas, 2001; Navis & Glynn, 2010: 441). While some researchers have idealized the outcome of this selection as a winner-take-all solution whereby the entire market will conform to the agreed-upon product configuration defined by the dominant design (Schilling, 1998), more researchers have recognized that the increased popularity of complex technological systems has added considerable complexity to the competitive dynamics surrounding dominant designs (Garud et al., 2002; Garud & Kumaraswamy, 1993; Teece, 2007) — in fact, even after a dominant design has emerged, competitors often follow closely behind to threaten the market leadership, as reflected in the continued battles between Microsoft versus Apple in operating systems, Intel versus AMD in microprocessors, and Google versus Yahoo in search engines.

Process models of dominant designs have suggested varied technological stages in the lifecycle of a discontinuous innovation. Anderson and Tushman (1990) divided the process of technological change into eras of ferment versus retention, suggesting systematic differences between them. Suarez (Suarez, 2004) conceptualized five major phases of a dominance battle — marked by a milestone (e.g., introduction of a product prototype or the emergence of a dominant design), "each phase is characterized by different dynamics that in turn make some of the factors associated with dominance more relevant than others." At the micro-level, firms undertake competitive actions to address various uncertainty and competitive threats caused by industrial dynamism and competitors in each market stage and seek temporary advantages over rivals by "strategic surprise, speed, and simultaneous and sequential thrusts" (Bettis & Hitt, 1995; Rindova, Ferrier, & Wiltbank, 2010: 1475). However, the problem with the conceptions of the process models of dominant designs is that they do not clearly reveal the co-evolvement of competitive dynamics with technological innovation, which calls for more research on how competition unfolds along the life cycle of dominant designs.

I believe the sustained work on competitive dynamics provides a useful lens to observe the competitive process associated with dominant designs. Rooted in the Austrian view of the market as a disequilibrium system, the competitive dynamics research argues that competitive advantage is temporary and dynamic, embedded in the streams of competitive actions that firms undertake to disrupt the market positions of competitors (Jacobson, 1992; Rindova et al., 2010; Schumpeter, 1934b, 1950). Because of the rapid changes in technological field, firms competing to define dominant designs must remain unconfined from traditional practices and to be receptive to new actions in the response to industrial dynamism and competitors' actions to succeed in new competitive landscapes in distinct technological stages (Bettis & Hitt, 1995; Chen, Lin, & Michel, 2010). As a result, the competitive dynamics will demonstrate different patterns as technology evolves along the life cycle.

To observe the overall characteristics of firms' competitive behavior, competitive dynamics research has underscored three attributes of competitive actions to define the aggressiveness of rivaling firms: *frequency* (i.e., number of actions undertaken), *magnitude* (i.e., resources committed to each action), and *complexity* (i.e., the different types of actions taken) (Ferrier, 2001; Rindova, Becerra, & Contardo, 2004; Yu, Subramaniam, & Cannella, 2009). In this paper, I discuss how the frequency and complexity of firms' competitive actions to ferment dominant designs co-evolve along the life cycle of technological discontinuities. I examine the influence of three factors: the *maturity* of the technological market, the *density* in the market category, and the *emergence of dominant designs* in the market category.

I tested the hypotheses using a sample of 145 market categories (with total 358 technological designs) sponsored by 253 organizations. I found that technological leaders sponsoring alternative designs compete more fiercely in the post-dominant design phase, in terms of both frequency and complexity of competitive action. The longitudinal observation suggests that the maturity of a technology-based market category — captured by the age of the market category — has strong implication on the pattern of competitive dynamics in a market category. Specifically, this research suggests that the frequency of action between technologies pursuing dominant designs follows an S-curve (first increase and then decrease) along the linage of a nascent market category; however, competitive complexity linearly increases over time as the market turns mature. I also found a strong association between patterns of competitive dynamics and density — i.e., the total number of competing technological leaders. I found density in general increases the frequency of action, but this association becomes weaker after the emergence of a dominant design. In contrast, I found a curvilinear (inverted-U shaped) relationship between density and action complexity.

CHAPTER TWO: RESEARCH ON TECHNOLOGY STANDARDS ACCOMPLISHMENT AND CHALLENGES

Technology standards are a characteristic of many industries, and the fate of firms may depend largely upon the outcome of the standard-based competition. The well documented competitive battles between Betamax and VHS (Cusumano, Mylonadis, & Rosenbloom, 1992) and Microsoft and Apple (Eisenmann, Parker, & Alstyne, 2006; Windrum, 2004) – to name a few —are illustrative of the phenomenon in their respective industries. In the management literature, scholars from different disciplines (e.g., industrial organization (IO) economics, strategic management, management of information science, and marketing) have examined technology standards, as well as the dynamics of standard-based competition, pursuing research streams employing concepts such as “standards” (e.g. Besen & Farrell, 1994; Cusumano et al., 1992; Farrell & Saloner, 1985), “dominant designs” (e.g. Srinivasan et al., 2006; Suarez, 2004; Tushman & Anderson, 1986) ,“platforms” (e.g. Economides & Katsamakas, 2006; Gandal, 1994; Kim & Kogut, 1996; Rochet & Tirole, 2003; Teece, 2007), “dominance battles” (e.g., Suarez, 2004), “technology races” (e.g., Lerner, 1997) or “systems competitions” (e.g., Hagedoorn, Carayannis, & Alexander, 2001; Katz & Shapiro, 1994).

The phenomenon captured by the concept of technology standards is indeed complex, as the evolution of standards involves both macro (environmental) and micro (firm) level forces, and standards both drive and are driven by the actions of firms and/or industry associations (Hemphill, 2009; Suarez, 2004). The complexity is reflected in the significant volume of work that has developed around standards in recent decades, where scholars pursued this broad phenomenon from their own necessarily narrow disciplinary perspectives. Thus the richness of the literature came at the cost of fragmentation caused by the inconsistent use of terms, and limited communication among scholars operating at different levels of analysis or treating standards as exogenous or endogenous variables. Further, there have been limited attempts at reviews and integration (Gallagher, 2007; Murmann & Frenken, 2006; Suarez, 2004). In one review, Murmann and Frenken (Murmann & Frenken, 2006) confined themselves to 24 studies of dominant designs, prompted by their interest in technology policy. In another, Suarez (Suarez, 2004) provided an integrative framework for managerial actions, an objective that precluded a focus on macro level issues such as industry evolution. The absence of integrative reviews has perhaps contributed to a paucity of conversations across research streams. The resulting fragmentation of literature may also have obscured the strategic importance of standards and in particular, the standard-based competition in management disciplines, judged partly by its marked absence in a major review of competitive dynamics (Ketechen Jr., Snow, & Hoover, 2004).

An integrative review of existing literature will facilitate conversations among research streams. The review will bridge works under different labels clarifying connections among them, organize the literature within a relevant framework summarizing the linkages and differences among levels of analysis, identify significant gaps in knowledge and distill opportunities for integration. Such a review will also allow standards scholars of different theoretical stances to reconcile contrasting theories and bring together dialectical interpretations of various facets of the phenomenon (Astley & Van de Ven, 1983).

Thus the primary objective of this paper is to provide an integrative review of the management literature on technology standards. We utilize Astley and Van de Ven’s

(Astley & Van de Ven, 1983) influential framework for organizing management theories to distinguish various strands of work in our domain. Astley and Van de Ven's framework is uniquely suited for our purpose because their scheme accommodates a) macro and micro levels of analysis, b) environmental selection, firm adaptation and strategic choice, and c) individual and collective actions of firms – all of which are not only relevant to the phenomenon of standards but have been the factors along which the literature has developed leading to the current state of fragmentation.

To accomplish our objective, we proceed as follows. In the next section, we outline the background of the literature on technology standards, highlighting the concept of standards, and standard-based competition. Next, we summarize the methodology for the selection of papers in our review and the rationale for the choice of our organizing framework. We then review the literature in this area which sets the stage for recommendations for future work. Finally, we summarize the major managerial implications that surface from our findings.

Background: Research on Technology Standards

What is a technology standard?

A standard can be defined broadly as the consensus of different agents to do certain key things with agreed-upon rules (Farrell & Saloner, 1992; Nickerson & Muehlen, 2006), and technology standard can be viewed as "a set of specifications to which all elements of products, processes, formats, or procedures under its jurisdiction must conform" (Tassey, 2000 :588).To understand the functional aspects of technology standards, it is helpful to consider the differences between supply and demand sides. On the supply side, a technology standard represents the synthesis of proven concepts on the design logics to organize the hierarchy and functional parameters for a particular type of product (Anderson & Tushman, 1990; Clark, 1985; Murmann & Frenken, 2006; Tassey, 2000; Tushman & Anderson, 1986; Weiss & Birnbaum, 1989). On the demand side, a technology standard reflects the desire of consumers for agreement on a uniform technological format that permits integration and interchangeability across multiple products (Axelrod, Mitchell, Thomas, Bennett, & Bruderer, 1995; Cusumano et al., 1992). Essentially, a technology standard represents the collective choice resulting from a balance between utility of consumers, technical possibilities and cost structure of manufacturers, and constraints of political, social, and economical institutions (Garud et al., 2002; Hargadon & Douglas, 2001; Tassey, 2000) .

In management literature, Utterback and Abernathy (1975) used the term "dominant designs" to refer to the technologies that achieve market dominance. Inspired by their work, a number of management researchers investigated technology standards under the label of "dominant designs" (e.g. Anderson & Tushman, 1990; Srinivasan et al., 2006; Suarez & Utterback, 1995), leading Gallagher (Gallagher, 2007) to conceptually distinguish dominant designs and technological standards[1]. For our purposes, we assimilate the literature on dominant designs within the more inclusive literature on standrads.

Research on standard-based competition

[1] Gallagher considered standards as narrowly driven by the importance of network effects while dominant designs have more to do with architectures. Gallagher also argued that standards are often important components of dominant designs.

Products involving technology standards have varying degrees of technological complexity, ranging from non-assembled simple products(e.g. light emitting polymers)to complex technological systems (e.g. computer) (Suarez, 2004). By observing relatively simpler products, researchers have identified a set of *technology*- and *market-based* facets of standard-based competition. Moreover, in view of the growing complexity of today' technological systems, especially in complex computer (West, 2003), telecommunication (Funk & Methe, 2001), and Internet-based industries (Waguespack & Fleming, 2009), the scholarly focus on *collective actions* to set standards have increased dramatically in the past two decades[2].

Technology- and market-based facets of standard-based competition

One facet of standards-based competition is based in technology: How technological evolution — captured by concepts such as technological lifecycle, technological discontinuity, and emergence of dominant technological design — shapes the competitive dynamics and structure of the industry. This line of thought originated with the studies of scholars such as Abernathy and Utterback (e.g., Abernathy & Utterback, 1978; Utterback & Abernathy, 1975), whose research led to the conceptualization of the emergence of technology standards (or in their words dominant designs) as cyclic processes of punctuated equilibria (Anderson & Tushman, 1990; Utterback & Suárez, 1993). Indeed, the punctuated equilibrium models of technological change are linked to the studies on the sociology of science and technology about the history of scientific progress (Kuhn, 1962; Suarez, 2004).

[2] We thank the anonymous reviewer who pointed out this to us.

In contrast, the *market-based* facet of a technology standard reveals how market mechanisms — in particular, "*network effects*" — drive the emergence of standards. Management researchers have incorporated the concept of network effects from the work of economists (Farrell & Saloner, 1985, 1986; Katz & Shapiro, 1994; Saloner & Shepard, 1995). Network effects, also known as "network externalities", are said to arise if a technology becomes more valuable as the number of users, or, the availability of complementary products, increases (Economides & Katsamakas, 2006; Farrell & Saloner, 1985; Katz & Shapiro, 1985, 1992; Liebowitz & Margolis, 1994; Suarez, 2004). Since network effects are built into the demand function, the competition surrounding standards follows dynamics that are considerably different from the competition without standards, requiring firms to pursue unconventional strategies, such as open architecture (Garud & Kumaraswamy, 1993) and/or free software (Armstrong, 2006), and sometimes can result in a winner-take-all situation (Katz & Shapiro, 1994) whereby the winning technology may drive all other technologies out of the market (Besen & Farrell, 1994; Schilling, 2002). The research on network effects has also provided economic reasoning to explain why radical innovation sometimes are considerably delayed in the presence of standards, as illustrated by the continued dominance of QWERTY layout in the keyboard market (Arthur, 1989; Katz & Shapiro, 1992).

Collective action in standard-based competition

A complex technological system often consists of a core technological base, or a *platform*, and numerous related pieces of technology developed separately by different manufacturers (Cusumano & Gawer, 2002; Murmann & Frenken, 2006). Since each technological system is supported by a co-specializing network of complementary actors collectively possessing the skills and resources required in the development of innovation, collective action is often required to set standards (Hargrave & Van De Ven, 2006; Wade, 1996). The firm controlling the core technology — i.e., the *platform* —is said to face two levels of challenges: (1) at the community level, the competitive threat imposed by competing platforms in the dominance battle; and (2) within the community, the coordination problem with various producers of ancillary products that expand the platform's market (Annabelle & Cusumano, 2002; Cusumano & Gawer, 2002).

To account for the role of complementary products in complex technological systems, some economists have advanced the concept of *two-sided markets* to address the strategy of firms controlling platforms (Economides & Katsamakas, 2006; Eisenmann et al., 2006; Gallaugher & Wang, 2002; Parker & Van Alstyne, 2005; Rochet & Tirole, 2006). In a two-sided market, the platform serves as the inter-mediating platform to connect two distinct, complementary user groups that are called (1) "sellers", who produce complementary products for the standard (or its competitor), and (2) "buyers", who desire the synergy of the standard (or its competitor) and various complementary products (Economides & Katsamakas, 2006; Eisenmann et al., 2006; Gallaugher & Wang, 2002; Parker & Van Alstyne, 2005; Rochet & Tirole, 2006). For example, a PC operating system connects the end users and software developers, and a video game console connects gamers and game developers. Competition in two-sided markets is complex because there are several reinforcing mechanisms at work. The buyers' utility of using an intermediating platform (e.g., a game console) increases with more sellers selling complementary products. At the same time, sellers are more motivated to produce complementary products for a particular platform if it attracts a larger number of buyers

(Rochet & Tirole, 2003). As a particular inter-mediating technology becomes increasingly adopted, the market tends to select the platform as the “standard” of the market, forcing all other platforms to exit (Armstrong, 2006; Eisenmann et al., 2006; Shapiro & Varian, 1999a). Thus, the firm controlling the platform may build coalition of systems assemblers, software vendor, and hardware manufacturers to enhance the adoption of its technology in the market (Hargrave & Van De Ven, 2006).

To capture firms’ interdependences surrounding a complex technological system, some researchers have developed the concept of “technological ecosystem” (Teece, 2007)(Teece, 2007)(Teece, 2007)[14][14][14][14][14][14] composed of one or a few core firms (often the “platform leaders”) and numerous periphery firms (Annabelle & Cusumano, 2002; Teece, 2007). The key decisions facing an ecosystem leader include (1) whether the standards needs to be open or proprietary, (2) whether the leader should financially invest in complementors to facilitate innovation, and (3) whether incentives should be provided to encourage the complementor’s investments. In view of the complexity of this strategic decision, Teece (Teece, 2007: 1332) argued that the success of firms facilitating standards will require “uncommon foresight and the ability to shape outcomes”.

Method of Review

To facilitate a coherent review, we followed the approach of Dahlander and Gann (2010) who used systematic searches and formal summaries of the literature to integrate major studies on a specific topic. We started with an exhaustive search for scholarly work[3] on technology standards. To find as many relevant publications as we could, we intentionally created a broad range of keywords for our search. We derived our list of keywords by extensively reading related literature and consulting experts in this area. The final list of keywords used in our search included: “dominant design”, “standard” , “platform”, “system”, “modularity”, “network externalities”, “two-sided markets” and “technological ecosystems”[4]. We searched the major journals[5] in the management field and then checked with the ISI database to make sure that we did not miss any highly cited work in this area [6]. This process yielded 567 papers after we dropped duplicates[7]. We then scanned each paper to assess its relevance to our topic. We used two criteria for exclusion. First, we excluded papers in which standards were not discussed. For instance, we dropped Bhaskaran and Gilbert’s (2005) study from our review because standards are not mentioned in the text. Second, we limited our sample to papers that discuss technology standards and those discussing other forms of standards, such as a management practice, were excluded. For example, we did not include Fischhoff’s (1984) paper on safety standards in our review because the paper does not focus on technology standards. Applying the selection criteria, we reduced the sample to 89 papers. All these articles have formalized technology standards as a key issue under investigation. We broke down our sample into two categories: theoretical (21 total) versus empirical (66

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[3] To make the research work more comparable, we focused on published journal articles and did not include books.
[4] Some keywords (e.g. “Standard”) were ambiguous and yielded too many irrelevant articles. So, in the searching process, we used “technology” with the “AND” option to exclude irrelevant articles. We compared the searching results by including and excluding “technology” as a required keyword for several years, and results were the same.
5 The journals involved in our initial search included: *Academy of Management Review*, *Academy of Management Journal* , *Administrative Science Quarterly* , *IEEE Transactions on Engineering Management* , *Journal of Business Venturing* , *Journal of Engineering and Technology Management* , *Journal of Management* , *Journal of Management Studies*, *Journal of Marketing* , *Journal of Marketing Research*, *Journal of Product Innovation Management*, *Management Science*, *MIS Quarterly*, *Organization Science*, *Research Policy*, *Strategic Management Journal*, and *The Business History Review*.
[6] This added a few papers from journals not involved in the initial search (Fee Figure 1).
[7] The search yielded duplicates because the author(s) may mention more than one keyword in the same paper.

total). For an initial overview of the literature, we graphically present the distributions of published articles by outlets in Figure 1 and over time in Figure 2.

We then proceeded to develop a detailed summary for each article in our sample, respectively for theoretical and empirical papers (See Appendix1 and 2). A review of the theoretical models and main findings in this body of literature indicated that research on technological standards is fragmented and covers a variety of topics through diverse theoretical lenses. To probe the coherence of this scholarly community, we employed the analysis used by Dahlander and Gann (2010) to portray the collaboration networks among authors. Figure 3 illustrates which scholars have coauthored with whom on publishing technology standards. Following Dahlander and Gann (2010) , we used "nodes" to refer to individual authors and "ties" to represent co-authorships. We normalized the nodes by the number of papers the authors have published on this topic[8].

Please insert Figures 1, 2 and 3 around here

Altogether 154 authors were involved in the scholarly community on technology standards. However, as the figure shows, the co-authorship network is fragmented. Even the most prolific authors, such as Tushman, Suarez, and Utterback, have been very limited in terms of collaborative research. The lack of extensive collaboration perhaps has led to the inconsistent use of terminologies in the literature, as well as difficulties in integrating findings across studies (Gallagher, 2007; Suarez, 2004), warranting an organizing framework for reviewing the literature.

[8] For each node, the larger the size, and darker the color, the more papers the author the node represents has published.

A Framework of Review

According to Ginsberg and Venkatraman (1985), an analytical framework is necessary for systematically evaluating the contribution of a given body of literature and discerning patterns. The literature on technology standards has invoked different ontological assumptions and focused on different levels of analysis. To accommodate the diverse perspectives, and to develop a systematic, coherent analysis of issues pertaining to technology standards, we utilized the organizing framework of Astley and Van de Ven (1983). As already mentioned in the introduction, this influential framework is ideally suitable to accommodate the divergent perspectives of scholars in the research on technology standards.

In view of the growing pluralism and complexity of organizational literature, Astley and Van de Ven developed a two-dimensional framework to conceptualize the fundamental approaches and debates of organizational theorists. This framework is based on two analytical dimensions: (1) the level of analysis (macro versus micro) and (2) the relative emphasis of research on deterministic versus voluntaristic assumption about the human nature of managers. The first analytical dimension, level of analysis, captures the differences between theories about a single firm (micro) versus those analyzing total populations of firms (macro). The second analytical dimension, deterministic versus voluntaristic orientation, addresses the distinctions between scholars who view firm behavior as determined by exogenous forces versus those who believe that firms act out of free will.

Crossing these two dimensions, Astley and Van de Ven offered four “central perspectives” in organizational theory: (1) *natural selection*, (2) *system structural*, (3) *strategic choice*, and (4) *collective-action*. The *natural selection view* assumes a deterministic role of managers and uses the macro-level phenomena as the unit of analysis to examine the "economic and technical dimensions of an industry that provide the context within which competition occurs" (Astley & Van de Ven, 1983: 250). Extending the deterministic assumption to micro-level analysis, the *system structural view* portrays the firm as a technically constrained system that must constantly adapt to develop a fit with the context. In contrast to the deterministic logic, the *strategic choice view* maintains that firms are "socially constructed, subjectively meaningful embodiments of individual action" (Astley & Van de Ven, 1983: 251) and therefore focus on the firm's proactive action to initiate both micro- and macro-level change. Following a similar voluntaristic assumption, the *collective action view* argues that firms may act collectively to achieve shared strategic purposes, and therefore focuses on how the collective action of a population of firms can generate change in the industry (Astley & Van de Ven, 1983).

Astley and Van de Ven's framework has had profound influence on management disciplines[9], primarily in the fields of organizational theory, strategic management and innovation management. The contribution of this work is twofold. First, the framework offers an overview of the basic architecture of research on various organizational phenomena, and by extension allows scholars of different assumptions and focal attentions to speak with each other to advance integrative understandings of reality. Second, by comparing and contrasting distinct views of underlying theories, the framework reveals the dialectical tensions among the theories, offering insights on six

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[9] The fact that this article has been cited 770 times in scholarly publications (up to August 2010) is one indicator of the comprehensiveness and fundamentality of this paper and its influence on management disciplines.

"central debates "that animate theory and are therefore biased towards specific parts of the reality of organizational life[10]. As Astley and Van de Ven suggested, both deterministic and voluntaristic views are "necessary for developing a dynamic appreciation of organizations" and to properly study organizations, one must go "across levels of analysis to understand the dialectical relationships between forces of conflict, coercion, and disruption at one level of organization [micro], and forces of consensus, unity, and integration at another level [macro]" (Astley & Van de Ven, 1983).

We chose this meta-theoretical scheme to organize our review for two reasons. First, the evolution of standards involves both macro (environmental) and micro (firm) level forces, and requires comparing and integrating studies at different levels of analysis. Second, standards both drive and are driven by the actions of firms (or firm groups / associations), and a review of this work should consider both the structural forms and the firm's proactive action (Hemphill, 2009; Suarez, 2004).A schematic framework to map these diverse approaches in the scholarly community will not only expose the diversity across studies but also (perhaps more importantly) reveal the linkages and overlaps between various lines of thought and thus facilitate conversations among different research streams.

Following Astley and Van de Ven (1983), we arrayed various papers on technology standards along two dimensions, with the first one based on levels of analysis (macro versus micro), and the other along the scholar's relative emphasis on the assumptions about the human nature (deterministic versus voluntaristic).In our review, we considered the level of analysis of a paper as "macro" if the paper focuses on a

[10] For more details about the central debates, see Astley and Van de Ven [1].

technological regime (Anderson & Tushman, 1990), or a standards battle (i.e., competition to define standards) (Besen & Farrell, 1994), and “micro”, if a paper focuses on a firm. We then assessed the authors’ assumptions regarding the deterministic versus voluntaristic orientation of the managers. We considered a paper as “voluntaristic” if the paper investigates how the firm, or a group of firms, initiates action to render a certain outcome. For instance, we considered Clymer and Asaba’s study (2008) as voluntaristic because the paper focuses on firms’ strategies to establish dominant designs. We also considered a paper as “voluntaristic” if the paper models industrial factors as the contingencies to moderate the impact of the firm's action on outcome (e.g., Suarez, 2004). In contrast, we considered a paper as deterministic if the firm’s action is viewed as the outcome of changes in the industry (e.g., Kim & Kogut, 1996), or not addressed (e.g., Tushman & Anderson, 1986).We also allowed a paper to have more than one perspective. These criteria enabled us to array all papers in our sample along the four central perspectives identified by Astley and Van de Ven (1983). Figure 4 offers a broad overview of the analytical foci, underlying logics, theoretical lenses, and managerial implications of each perspective.

Please insert Figure 4, Table 1

In addition, themes emerged in each perspective as we proceeded to review the papers in more detail. Table 1 offers summaries of the major mechanisms and key arguments of the themes, arrayed along the four central perspectives. Moreover, using these themes as a coding scheme, we coded all the articles in our sample to reflect the central perspective(s) of each study and the major theme(s) it explores. We first had the two authors code the articles separately and compared the overall agreement between their coding (greater than 80 per cent). We then incorporated in-depth discussions to resolve the discrepancies, leading to unanimously agreed-upon coding results (see Appendix 1 and 2). We repeated the coding procedure after the completion of the manuscript, and since we obtained consistent results, we were confident of the reliability of our coding.

We then developed a graphic presentation of the distributions of papers by theme in Figure 5. Furthermore, since the themes explored in a same paper may incorporate more than one central perspective, we used two Venn diagrams, one for theoretical papers and the other for empirical papers, to visualize the distribution and overlap of the standards literature along the four central perspectives (See Figures 6 and 7).

Please insert Figures 5, 6 and 7 around here

Overview of Literature

Our review revealed a number of themes in the literature on technology standards. In this section, we first discuss the themes within the four central perspectives indentified by Astley and Van de Ven (Astley & Van de Ven, 1983) and then focus on the limited number of studies that have incorporated multiple perspectives.

Natural Selection View (macro level, deterministic orientation)

Theorists studying technology standards based in this perspective believe that strategic flexibility of firms in the face of standards is limited by environmental characteristics. Therefore, technological change and the emergence of standards follow a deterministic path and the role of management is not a focus in this view. A review of the literature yielded three related themes in this view: 1) *process models of technology change*, 2) *factors that lead to the emergence of a standard*, and 3) *industry structures*.

Process models of technology change

Technology change is often associated with fierce competition and the shaping and reshaping of the industries and firms (Abernathy & Clark, 1985; Abernathy & Utterback, 1978; Anderson & Jolson, 1980; Rogers, 1983; Schilling, 2000; Utterback & Abernathy, 1975). In an attempt to conceptualize the pattern of this change, Dosi (1982) argued that the process of technology change resembles the process of “paradigm shift” in the scientific field articulated by Kuhn (1962): continuous changes in an established paradigm (represented by a dominant technological trajectory or technological regime) are interrupted by major scientific breakthroughs and the rise of new paradigms stems from the interplay between scientific advances, social institutions, as well as economic forces.

Similarly, Tushman and Anderson (1986) proposed a model of punctuated equilibrium. In this model, technology evolution is a cyclical process characterized by long periods of incremental improvements punctuated by technological discontinuities. Each technological discontinuity is followed by an “era of ferment,” during which fierce competition takes place among technological variants until a dominant design, or a standard, is selected and alternative technologies are locked out (Anderson & Tushman, 1990; Schilling, 1998, 2002; Wade, 1996). Anderson and Tushman (1990) further argued that the competition in the era of ferment is characterized by two distinct selection processes: the replacement of entrenched technological regimes by emerging technological regimes and the rivalry between alternative designs embedded in new technologies.

Furthermore, if technology change involves the innovation of complex technological systems, the process of standard-based competition can be even more complex (Funk, 2004). In this case, each technological design constitutes a technological community (a technology regime) that contains core firms controlling the basic design and periphery firms that have a stake in the core technology. Wade (Wade, 1995, 1996) suggested that firms' entry into and exit from these technological communities are a function of the population density and the emergence of technology standards. Kogut, Walker, and Kim (1995) suggested that the more the potential partners and customers using a standard, the higher the number of new entrants into a technological regime.

Factors that lead to the emergence of standards

The driving forces of a technology standard are a mixture of numerous factors. In addition to technological superiority, factors such as network effects, switching costs, government policy, and intellectual property regimes, as well as other environmental factors, play a major role (Anderson & Tushman, 1990; Arthur, 1996; Funk, 2004; Srinivasan et al., 2006).

First, in the presence of *network effects*, the ferment and emergence of technology standards will depend substantially on the installed base — a significant advantage in the installed base allows a product to dominate competitors increasingly until it locks out all alternatives, creating a phenomenon called "bandwagon" which eventually leads to "winner-take-all" (Lee, Lee, & Lee, 2006). The development of a large installed base is embedded in a set of strategic factors such as licensing policies (Economides &

Katsamakas, 2006), compatibility with other systems (Tassey, 2000), the availability of complementary products (Gandal, Kende, & Rob, 2000) , and/or the decision regarding whether to pursue an open source strategy (Casadesus-Masanell & Ghemawat, 2006). In spite of this theorizing, empirical studies have provided contradictory findings about the role of installed base in standardization. Cottrell (1994) suggested that installed base plays a critical role in the development of technology standards and the uniform standard in the U.S. computer software embodied difficulty moving to new standards. In contrast, Stremersch and co-authors (2007) reported that network effects from the installed base (availability of complementary products) are actually weaker than expected in the literature, and that hardware sales are likely to lead software availability rather than the reverse. In addition to installed base, researchers also revealed that other network-related factors, such as network topology and density, are related to the rise of network effects (Weitzel, Beimborn, & Knig, 2006).

Second, *switching costs* offer another explanation for why technology standards emerge, particularly why an accepted standard may lock in the market even though a newer, superior technology is available. The adoption of the new technology may imply substantial investment in terms of hardware, software, or special technical skills, and the loss of existing networks, creating switching costs to inhibit the adoption of a new technology (Bonaccorsi, Giannangeli, & Rossi, 2006; Chen & Forman, 2006; Farrell & Saloner, 1985; Forman, 2005; Zhu, Kraemer, Gurbaxani, & Xu, 2006). Due to the mixture of network and non-network based switching costs, the market for a technology standard is characterized by *excess inertia*[11](Katz & Shapiro, 1992) , *path dependence*[12]

[11] A network market is said to have excess inertia if the market is biased towards existing products.

(Mazzoleni, 1997; Takahashi & Namiki, 2003) and *lock-in*[13](Arthur, 1989; Liebowitz & Margolis, 1995; Loch & Huberman, 1999).

Third, *government policy and intellectual property regimes* influence the emergence of technology standards. Takahashi and Namiki (Takahashi & Namiki, 2003) suggested that government policy should, on the one hand, permit collaboration required for technology innovation, while one the other hand, prosecute clear violations of antitrust law to intervene into the process for de facto standards to emerge. If strong intellectual property rights hinder innovation, the authorities need to bring antitrust action. Bekkers and co-authors (Bekkers, Duysters, & Verspagen, 2002) revealed that dominant players' position in the network is based on ownership of essential intellectual property rights (IPRs) and that there is a positive relationship between market power and essential IPRs and network centrality. A related topic is open system strategy. Lecocq and Demil (Lecocq & Demil, 2006) found that open systems may lower the entry barriers for complementary producers by conferring partial or total access to proprietary knowledge, which reduces switching costs.

Finally, environmental factors other than to regulatory forces, such as appropriability and environmental munificence, are also found to be relevant to the ferment of technology standards (Anderson & Tushman, 1990; Tushman & Anderson, 1986). Anderson and Tushman found that a single dominant technology is more likely to emerge following a technological discontinuity in low appropriability regimes. Similarly,

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[12] Path dependence represents an alternative analytic perspective in economics, arguing that a minor advantage or inconsequential lead for some technology or product in the earlier stage have profound influence (set the path) on the allocation of resource in the market in the later stage.

[13] Lock-in is the result of inherent self-reinforcing dynamics, referring to the state of irreversibility and total inflexibility.

Srinivasan and co-authors. (2006) found that standards (dominant designs) are more likely to appear in industries with weaker appropriability, lower radicalness of innovation and higher R&D intensity. The same authors also found that the intensity of competition shortens the time needed to select a dominant design.

Industry structures

Natural selection researchers observed that standards are associated with the *winner-take-all* dynamics. Once a standard emerges, it will be entrenched in distribution channels and the minds of customers, reduce the price of new technology through economies of scale, and attract the vast major of software and peripherals for compatibility with the standard (Anderson & Tushman, 1990). Due to network effects, a winning standard will govern a large user base and the more it gains prevalence, the more likely it will emerge as a sole technological design in a given technological field (Arthur, 1996). However, Lee, Lee, and Lee (2006) cautioned about the use of the “winner-take-all” notion, arguing that the outcome might depend on the structural characteristics of a customer network. Eisenmann, Parker and Alstyne (Eisenmann et al., 2006) argued that three conditions for winner-take-all to occur: (1) It is costly for users to adopt more than one technology; (2) Network effects are positive and strong; (3) Users do not have strong preferences for special features.

As we previously mentioned, the study of network effects also revealed a two-sided market structure for technology standards. In the presence of abundant cross-side network effects between the two sides of a network market, a platform sponsor may employ a “getting-both-sides-on-board” strategy. For example, a platform sponsor may provide easy access to users of one side of the market, and thus strategically construct a “loss center”, to ensure a significant amount of cross-network effects. This explains some unconventional pricing and technology strategies of firms who are willing to give out free products or subsidize related products without expecting future exploitation of these market segments (Parker & Van Alstyne, 2005).

Some natural-selection papers have investigated the impact of standardization on the shape of the industry’s demand curve. Brynjolfsson and Kemerer (1996) found that in the spreadsheet industry, higher prices are associated with spreadsheets providing a higher degree of compatibility. Chakravarti and Xie (2006) found that consumers are less likely to purchase a new product when there is competition for a standard.

Finally, several studies have suggested that technological change and the emergence of technology standards may influence firms’ entry into and exit from the industry. Tushman and Anderson (Tushman & Anderson, 1986) found that technological change influences the entry-to-exit ratio in the industry, whereby competence-enhancing technological discontinuities will be associated with decreased entry-to-exit ratios and this pattern will be reversed for competence-destroying discontinuities. Lecocq and Demil (2006) found that new entrants adopt open systems more readily than incumbents, resulting in a decrease in the average size of firms in the installed base.

Summary

In addition to process models, studies in the natural selection view proposed several theoretical links among the concepts discussed above, as shown in Figure 8. As shown in the figure, the emergence of technological standards is associated with a set of industrial outcomes captured by concepts such as winner-take-all, demand curve and firms’ entry and exits. Drivers of technology standards are documented in three blocks of factors — (1) technological regime, (2) institution / environment and (3) market mechanisms. Although not fully explicated in the literature, the influence of these factors appears to be contingent on the complexity of technological system — compared with simple products, complex technological systems may demonstrate different patterns of technological evolution, have different requirements for institutional / environmental factors, and follow distinct market mechanisms.

System Structural View (micro level, deterministic orientation)

Research from this perspective has focused on how firms play the "survival-of-the-fittest" game in the face of technology standards — i.e., firms' adaptive strategy. Studies in this view have shed light on three facets of firms' adaptation: (1) *time-related*, (2) *technology-based* and (3) *market-based*.

Time-related adaptation

Utterback and Abernathy (Utterback & Abernathy, 1975) suggested that technological change follows systematic patterns and involves several stages along the timeline. The firm's key task in this process is to develop the *fit* with different requirements in each technological stage, whereby its overall efforts in innovation should move from product towards process innovation. Utterback and Suarez (Utterback & Suárez, 1993) argued that firms are not born to win or lose the natural selection associated with technological change; rather, incumbent firms may react by adjusting their administrative and production structures in accord to dynamics of industrial innovation to become the surviving ones. For new comers, selecting the right time to enter a technological industry is critical. This notion inspired several empirical studies with contradictory findings. Suarez and Utterback (1995) found that the probability of survival tends to be higher for firms entering the industry before the emergence of a technology standard than for firm entering after it. Whereas Christensen and co-authors (Christensen et al., 1998) reported similar findings, Tegarden and co-authors (Tegarden et al., 1999) found that firm survival in the face of standards not only depends on time of entry but also significantly on technology-based adaptation.

Technology-based adaptation

Firms' technology-based adaptation involves several strategic decisions. The first concerns the decision to incorporate the technological features of a standard in product design. Christensen and co-authors (Christensen et al., 1998) found that in the disk drive industry, firms incorporating what became the dominant design have had much higher probability of survival than firms that ignored such features. However, other researchers suggested that firms are not necessarily doomed even if they chose the wrong design initially — firms shifting to the dominant design in a later stage still have the chance to survive (Tegarden et al., 1999). Second, if a standard is embedded in a complex technological system, the adaptive firm's profitability will depend on the extent to which its product is compatible with (1) other products of the same type and (2) various complementary products in a hardware/ software network (Sheremata, 2004). Xie and Sirbu (1995) suggested that compatibility with a dominant player is beneficial for new firms. Such a notion received support in the empirical work. In a study on the video game industry, Venkatraman and Lee (2004) found that a software developer is more likely to work with a platform with a dominant market position. Finally, Bonaccorsi and co-authors (2006) suggested that firms tend to use hybrid business models to adapt to an environment dominated by open standards, and the degree of openness toward open standards is affected by organizational factors such as those of organizational size and age.

Market-based adaptation

Incorporating the concept of network effects, Srinivasan, Lilien, and Rangaswamy (2004) found that network effects may both positively and negatively influence the survival of firms. They found that if a firm adopts a new technology early, the influence of network effects is contingent on several other factors such as the radicalness of the new technology, technological intensity of products, and the incumbency of the firm. In addition to network effects, switching costs represent additional market mechanism to influence firms' adaptation. Sheremata (2004) argued that the profits of firms introducing radical innovation to the market depend on how much switching costs of the new technology — such challengers must provide value that exceeds the cost of switching; otherwise, consumers will not switch.

Summary

The system structural view on technology standards is essentially embedded in contingency theories of organization, which link environment, firm characteristics and firm performance. These studies have addressed two sets of questions: (1) "how does the firm react to technological change and the emergence of a technology standard?" and (2) "what are the performance implications of the firm's adaptive strategy?" Figure 9 offers a summary of the findings from distinct studies: In the competition related to technology standards, factors in the technological regime are the main drivers influencing firms' adaptive strategies, which in turn influence micro-level (organizational) outcomes. Two sets of contingencies have been revealed to be at work: first, firm resources may serve as a moderator of the way firms adapt to technological change and standards; second, the institution / environment and market mechanisms may serve as a moderator of the linkages to the effectiveness of firms' adaptation.

Strategic Choice View (micro level, voluntaristic orientation)

In the standards literature, theorists of the strategic choice view argued that competitive advantage in standardization is not merely a function of environmental determinism, but also a function of firm strategy and resources (Cusumano et al., 1992; Funk, 2003; Gallagher, 2007; Khazam & Mowery, 1994). Researchers in this arena have highlighted five major aspects of firms' strategic choices in the face of technology standards: 1) *institutional entrepreneurship*, 2) *technology and product strategies*, and 3) *the role of resources*.

Institutional entrepreneurship

Several researchers suggested that technology change goes beyond a technical issue to involve substantial change in the otherwise stable institutional landscape (Garud et al., 2002; Hardy & Maguire, 2008; Hargadon & Douglas, 2001; Maguire et al., 2004). Thus, firms pursuing standards can be thought of as "institutional entrepreneurs" whose innovation is intended to dislodge established institutions in the technological field. Hargrave and Van de Ven (2006) summarized four sets of challenges facing an institutional entrepreneur. The first is the *framing contest* — technological change introduces rivaling new technological, therefore, an institutional entrepreneur will compete to establish the legitimacy of its own technological trajectory in the public domain. The second challenge is to *enact a collaborative network* of firms whose products and/or services are critical for the success of the core technology standard controlled by the institutional entrepreneur. Third, the institutional entrepreneur must facilitate *institutional arrangements* such as regulating systems and resources allocation. Finally, the institutional entrepreneur must enact the *political and collective processes* through which standards emerge.

Several case studies have described the role of institutional entrepreneurship in the emergence of technology standards. Cusumano and co-authors (1992) provided detailed information regarding how the coalition initiated by JVC facilitated the VHS-based strategic alliances which eventually made the market select VHS over Betamax format as the standard for videocassette recorders. Hargadon and Douglas (2001) found that to launch technological change, it is crucial for institutional entrepreneurs to incorporate concrete designs in the early stage of the new technology to invoke public's familiarity with existing technologies, but without losing the ability to replace them. Garud and co-authors (Garud et al., 2002; Garud & Kumaraswamy, 1993) revealed built-in tensions in established technological fields due to enabling and constraining effects forged by in-depth cooperation among competitors.

Technology and product strategies

Strategic-choice studies have addressed four sets of technology and product strategies used by firms in setting technology standards: 1) *proprietary versus open platforms*, 2) *bundling and compatibility strategies*, and 3) *learning and innovation*.

Proprietary versus open platforms. Providing rivals easy access to the firm's core technology represents an unconventional strategy to set standards (Garud & Kumaraswamy, 1993). Yet the degree of *openness* varies substantially across firms ranging from purely proprietary (e.g., closed system) to completely open (e.g., open source), which is mainly reflected in the licensing policy (Suarez, 2004). If a firm decides to pursue open standard, the most extreme case of licensing, the firm will make its technology completely available for free (e.g., Sun Microsystems). Khazam and Mowery (1994) found that in the case of Sun Microsystems, this strategy contributed to the establishment of Sun's SPARC architecture as the dominant design in the workstation market. The downside of the open architecture strategy is that it may significantly reduce network-related entry thresholds and stimulate cooperative input to advance the technological offerings of a standard. In addition, open strategy may result in a poor appropriability regime, leading to constraints on the standard-setting firms' sustained competitive advantage (West, 2003). In contrast, if the firm is committed to protecting intellectual rights, a strategy somewhat opposite to open standard, it is less likely to actively engage in standardization processes (Blind & Thumm, 2004).

Compatibility and bundling strategies. A firm's compatibility strategy is embedded in the technological design that allows its product to be used with other products (Suarez, 2004). Large complex technological systems require system-wide compatibility and integration. Thus, for innovative firms that wish to shift the locus of standards from an existing core system to a new one, the support of compatible subsystems becomes functionally critical (Soh & Roberts, 2003). Moreover, in the market, compatibility induces users to converge around a single technological system rather than support multiple systems, which forces one technology to become dominant overtime (Schilling, 2002).

Bundling is to sell two or more separate products in a package (Stremersch & Tellis, 2002). In setting standards, firms can leverage the installed base of an established product by bundling a new, compatible product to it. This strategy can be decisive in the standards battle. In the competition with Netscape to set a standard for Internet browsers, Microsoft's bundling strategy gave it a competitive edge — the additional installation requirements of Netscape Navigator implied a cost, whereas Microsoft IE was automatically bundled with the operating system (Windrum, 2004).

Learning and innovation. In setting standards, other things being equal, the firm offering a better technology than rivals has higher likelihood to become dominant (Suarez, 2004). For firms controlling complex systems, integrating know-how from outside and within the firm is especially important — the creation of learning, knowledge-sharing, and knowledge integration are critical to business performance (Teece, 2007). Empirically, Schilling (2002) found that continued learning seems to decrease firms' likelihood of lock-out. Warner and co-authors found that (Warner, Fairbank, & Steensma, 2006) firms can reduce uncertainty and steer standardizing processes by acquiring relevant knowledge through merger and acquisition.

Role of resources

In addition to technological superiority, other forms of firm resources, such as complementary products and installed base, are critical in setting technology standards (Suarez, 2004). First, empirical studies have suggested that the availability of complementary products plays a key role to the success of technology standards. Cusumano and co-authors (1992) suggested that the availability of VHS-based movies represented a decisive factor to establish VHS' leading position in the VCR market. Schilling (Schilling, 2002) found that when the availability of complementary goods is lower, firms competing in network markets are likely to suffer a competitive disadvantage. Second, researchers have provided evidence that the installed base of a firm's technology is a critical factor to drive the firm's success in setting technology standards (Schilling, 2002). Moreover, some researchers suggested that firms might also benefit from network-related resources in standard-based competition. Funk (2003) suggested that NTT DoCoMo and its suppliers used information advantages that heavily influenced dominant design. Finally, some researchers highlighted the importance of appropriate resources allocation in standard-based competition. Clymer and Asaba (2008) suggested that a manufacturer of a complex product should pay attention to the deployment of technology resources to generate higher revenue growth.

Summary

The basic logic of the strategic choice studies is that firms' strategic actions initiate technological change and the emergence of standards in the industry. As shown in Figure 10, these studies have portrayed the emergence of technological standards as driven by three blocks of firm-level factors — (1) institutional entrepreneurship, (2) technology / product strategies, and (3) firm resources. The influence of micro-level factors on the emergence of technological standards is found to be contingent on several factors related to institution/environment and market mechanisms.

Collective-Action View (macro level, voluntaristic orientation)

With a collective-action model, technology change can be viewed as a dialectical process in which coalition of partisan actors espousing conflicting views confront each and engage in political behaviors to create and change standards (Hargrave & Van De Ven, 2006). The emergence of a standard reflects the collective actions of firms that have a stake in the technological regime that create not only technology standards, but also new institutional structures to impact macro-and micro-levels of innovation performances (Economides & Katsamakas, 2006; Hargadon & Douglas, 2001; Hargrave & Van De Ven, 2006; West, 2003). The empirical literature on collective action in setting standards has given us insights into: (1) *drivers of collective action*, (2) *forms of collaboration and competition*, and (3) *mechanisms in the creation of standards*.

Drivers of collective action

Extant research has suggested three major drivers of collective action in setting technology standards: (1) *complexity of technological systems*, (2) *governmental action*, and (3) *the motives of the firm*.

Complexity of technological systems. Facilitating standards in complex technological systems requires the collective efforts of various agents including in-and out- house innovation units, manufacturers of core and periphery components, the government, industrial associations, all firms that have a stake in the emerging technological regime, and various technology users (Lee & Lim, 2001). Van den Ende and Kemp's (1999) review of the computer industry indicated that computer technology is developed as a result of collective action in which agents within the same technological regime are connected to incorporate changes in user practices, the development of new skills, software, and the changing definition of a computer. In a study on VIP standardization efforts, Markus, Steinfield, Wigand, and Minton (2006) proposed that standard makers must ensure the collective participation of representative members of user groups, and evaluate the likelihood that other firms will commit to the development of the same standard.

Governmental action. Case studies also revealed the role of governments in facilitating collective action. Cottrell (1994) outlined Japanese and the U.S. governments' different public policy efforts to distinct short- and long-term problems in the Japanese versus the U.S. software industries. Japanese firms lagged in the near term and faced with the problems posed by multiple standards, however, these challenges aided long-term adaptability and performance of the Japanese industry. In contrast, the U.S. industry benefitted from a single dominant standard, but has experienced difficulty moving to new standards. Funk and Methe (2001) suggested that governments may exert influences on the forecasted and actual installed base for a technological system, the amount of competition in the market, and the number of and degree of openness in the standards, which in turn regulates the cooperation and competition in the standards battle.

The motives of the firm. Empirical studies also examined firms' motivation for collective action. One line of work has focused on the role of "institutional entrepreneurs" to formulate collective action with firms whose technology complements and co-evolve with the core technology (Garud et al., 2002; Hargrave & Van De Ven, 2006). Researchers found that these firms' decision to participate in collection action may depend on the firms' technological capability (Blind & Thumm, 2004) and the amount of uncertain in the technological field (Kogut et al., 1995). In a study on participating firms in open source communities, Waguespack and Fleming (2009) found that by actively participating in setting open source standards, firms may influence the standardization processes and in turn increase their performance. Soh (Soh, 2010) suggested that firms attract the complementary manufacturers by building alliance networks to favor an intended technology standard. In this process, firms with high ego network density, together with a strategic purpose for knowledge acquisition and sharing within the technological community, achieve better innovation performance.

Forms of cooperation and competition.

Since complex technological systems consist of nested platforms, subsystems and components (Murmann & Frenken, 2006), the competition for standards occurs at the community rather than at the firm level. This adds substantial complexity to inter-firm relationships in the standards battle. As the number of firms in a technological community increases to a critical mass, a mixture of cooperative and competitive relationships among these firms begins to accumulate. The collective action of this emerging network, composed of "institutional entrepreneurs" (Garud et al., 2002) or "platform leaders" (Annabelle & Cusumano, 2002),and firms performing diverse roles in the community, eventually will transform the technological community into a commercially viable industry (Hargrave & Van De Ven, 2006).

In the case of complex technological systems, the cooperation and competition for standards among technological communities often has a hierarchical structure (Van de Ven, Polley, Garud, & Venkataraman, 1999: 169). On top of the hierarchy is the competition between technological leaders — i.e., firms controlling technological platforms and standards. In the early stage of technological change, fierce competition may occur at this level and firms within a technological community must cooperate to lock out firms from competing communities to create new institutions in the industry (Garud et al., 2010; Garud et al., 2002; Hargrave & Van De Ven, 2006). In the later stage of technological change, even firms from competing technological communities may collaborate (Hagedoorn et al., 2001). In the personal computer industry, for example, the current standard is IBM and Microsoft personal computing architecture, which dominates the other version of personal computing, represented by the Macintosh computers by Apple. However, there have been an increasing number of alliances between IBM and Apple. Joint development of innovation appears to be a major objective of these alliances. Yet the timing of cooperation between technological leaders is critical — indeed, the technological partnering between two competing technological regimes, Macintosh of Apple and DOS-based design of IBM and Microsoft, has only occurred after the latter had become the standard (Hagedoorn et al., 2001).

Competition may occur between open-source versus proprietary platforms. A proprietary platform involves an architecture of related standards, sponsored by one or more technological leaders (West, 2003). West (West, 2003) suggested that firms' profits from innovation depends on the appropriability regime associated with IPRs. In the absence of such IPR protection, firms must use some combination of speed, timing and luck if they hope to appropriate returns. Nevertheless, open source represents a different approach. Instead of using IPRs to set boundaries between vendors and their competitors and customers, open source software facilitates collaboration of all agents, maximizing adoption throughout the value networks.

Mechanisms to create standards

It is common for firms to "strategically maneuver" the market mechanism to shape and facilitate adoption of *de facto* technology standards (Axelrod et al., 1995). The standardization of Java, a complex technological system that enables computers to run applications distributed over a network, had much to do with the coalition of Sun Microsystems with numerous systems assemblers, software firms, and computer manufacturers, as well as the International Organization for Standards and the European Computer Manufacturers' Association. Collective action allowed Java to break away from Unix and to challenge the dominance of Microsoft's Windows (Garud et al., 2002; Hargrave & Van De Ven, 2006; Takahashi & Namiki, 2003). Two other examples, the VHS alliance coordinated by JVC to sponsor a video recorder standard and the technical workstation alliances to sponsor Unix operating system standards, provide additional insights on the same phenomenon(Axelrod et al., 1995).

Committees represent the *de jure* mechanisms to create technology standards through collective action. Funk and Methe (2001) distinguished between two types of committees: *governmental* and *industrial-based*. Governmental committees can carry tremendous weight to support a standard, superceding the market processes; whereas industrial committees must be supported by firms in addition to governments. By comparing the standardization processes in the telecommunication market in the U.S. (more market-based) versus Japan and Europe (more committee-based), Funk and Methe (2001) found that without the actions of committees, the market may be slower for a standard to emerge when technological change occurs, particularly if substantial investment in infrastructure is required.

Researchers also revealed other social mechanisms in collective action that drive the emergence of technology standards. Building on Bijker, Hughes, and Pinch (Bijker, Hughes, & Pinch, 1987), Hargrave and Van De Ven (Hargrave & Van De Ven, 2006) suggested that the emergence of a technology standard may be a result of negotiation among relevant social groups. Except for a few simple technologies, the acceptance and innovation of dominant technology is seldom a function of technological determinism —

instead, standards emerge out of a sociopolitical process of compromise and accommodation played out in the community. To cope with these tensions, sponsors of new standards must co-opt the standardization process by means of impression management, sense-making, legitimation, and appealing to authority to change the "rules of the game", as well as loosening the coupling between institutions and their stakeholders (Garud et al., 2002; Garud & Kumaraswamy, 1993; West, 2003).

Summary

In Figure 11, we summarize the findings in the collective action view. Collective action — captured by concepts such as alliances, industrial consortium or standard setting bodies, and hybrid models — is driven by three blocks of factors — (1) technological regime, (2) institution / environment, and (3) motives of the firm. Collective action leads to *both* macro- and micro-level outcomes. At the macro-level, collective action can shape technology standards, but at the same time, intensify competition between cooperators. At the micro-level, collective action influences both the individual firms' decision to join the industry as well as their performance. The formulation of collective action and the way it influences the macro- and micro-level outcomes are contingent on the institutional and market factors.

Studies based in multiple views

Our review also identified some studies based in more than on view. These studies generally fall into three clusters: 1) incorporating both natural selection and system structural views, 2) addressing factors related to both natural selection and strategic choice; and 3) assessing the relative importance of collective action and strategic choice of individual firms. In the first, the contingency concept of *fit* is invoked to explain the performance. The degree to which internal characteristics of the firm (e.g. resources and processes) are matched to the environment (including technological domain) is predicted to be the causal agent behind performance (e.g., Utterback & Suárez, 1993). In the second case, both market and technology factors as well as strategic actions (e.g., timing of entry) are jointly hypothesized to predict performance (e.g., Suarez, 2004). Finally, as an extension of the line of thought among standards researchers in terms of whether standard-setting requires "individual action" or "collective action," some scholars (e.g., Waguespack & Fleming, 2009) have pointed out that open source communities are an important contingency that bridges the strategy of individual firms and collective actions of firm as an interdependent group.

Discussion

Our review of the standards literature has underscored the fragmentation of this literature, partly because of the differences in perspective of the researchers and the absence of conversations among them. The differences in perspective are reflected in the flow of logic, specific concepts invoked and sometimes even the research methods utilized in different streams. We have summarized the findings under broad unifying constructs (e.g., technological regime, institution / environment, market mechanisms, see Figures 8-11) with an eye to offering pathways to integration. The absence of conversations across perspectives is reflected in the choice of variables by researchers in distinct views: in spite of the relevance, many variables are unitarily conceptualized in one view and are absent in other views — e.g., population density (natural section view), survival (system structural view), network position (strategic choice view), and co-opetition (collective action view).

It is possible that these differences reflect differences in the problems being addressed by the researchers.[14] For example, some researchers have used a natural selection view because they focus on dominant designs that do not involve strong network effects; others have used a micro view because they are addressing standards in a simple products such as CD's and video systems; still others have taken a collective action view because they have addressed standards in complex technological systems. This possibility augurs well for efforts at integration: by encouraging conversations among scholars from different perspectives we may arrive at increasingly integrated understanding of the standards phenomenon.

But before we discuss fruitful avenues for needed integration, we provide a brief evaluation of the literature along five themes: 1) Unevenness in the development of literature; 2) Differences in the flow of logic; and 3) Research methods.

Unevenness in the development of the literature

As shown in Figures 6 and 7, both theoretically and empirically, the natural selection view is most developed followed by the strategic choice view. Albeit with different logics, researchers in these perspectives have pursued a pattern of systematic accumulation of research. Empirical works have dominated the collective action view, where there has been a conspicuous absence of theoretical work. The system structure view has attracted relatively limited attention and hence the promise of informing organizational adaptation in the face of technological change and the emergence of standards remains only partly fulfilled.

[14] We thank one of the anonymous reviewers for bringing this point to our attention.

In addition to the uneven development sketched above, there has been a singular paucity of works that utilize more than one perspective. Indeed, the standards phenomena is a complex one (Hemphill, 2009; Suarez, 2004); therefore, research utilizing multiple perspectives is particularly valuable to enhance our understanding. While the limited number of works invoking multiple perspectives relied on contingency models, this current fragmentation of the literature may be framed as a major opportunity to move us closer to an integrative understanding of this complex phenomenon.

Differences in the flow of logic

The emergence of standards occupies a focal point in all perspectives. However, as the figures reveal, the four perspectives differ in terms of the flow of logics that underpin the explanation of standards emergence. We highlight four major differences:

1. In the natural selection view, the emergence of standards is driven by technological, institutional / environmental, and market factors whereas the strategic choice view considers standards as the result of firm's proactive actions, captured by entrepreneurship and competitive strategies / resources. The collective action view is characterized by an additive model combining both macro- (e.g., technological regime and institution) and micro-level factors (e.g., firm entrepreneurship and strategy). In the system structure view, the emergence of standards is considered as an external contingency.

2. The natural selection view is also concerned with other macro-level outcomes such as industrial structure (e.g., winner-take-all) and firms' entry and exit. Some collective action studies have addressed the micro-level outcomes such as participating firms' performance. In the system structure view, the emergence of standards is not considered as an outcome. Most of the system structure studies have focused on the effectiveness of firms' adaptive strategy in the face of standards.

3. The role of institutional / environment factors is also different across the four views. In the natural selection view, institutional / environmental factors (e.g., IPRs) are direct drivers of standards. However, in the system structure and strategic choice views, these factors are modeled as contingencies influencing the impact of firm action on macro- and micro-level outcomes. The collective action view considers these factors as both the drivers of standards as well as contingencies.

4. Firms' resources are relevant in the system structure and strategic choice views. In the strategic choice view, a set of firm-specific resources is drivers to determine the outcome of the dominance battle. In contrast, firm-specific resources are conceptualized as moderators in the system structure view to influence the S-C-P relationships.

The differences among perspectives are also reflected in the research methods.

Research method

Table 2 provides a summary of research methods across perspectives. Research in the natural selection view has displayed a wide diversity of research methods: case studies and quantitative research using archival data, followed by some survey-based works and limited research utilizing other methods (e.g., interviews and simulation). The system structure view has manifested a conspicuous lack of variety in research methods — except for a small number of survey-based studies, most works in this view have pursued quantitative research designs using archival data. The strategic choice view resembles the natural selection view by clustering in case studies and quantitative research using archival data but differs from the latter as it has characteristically more interviews and fewer survey-based works. Finally, in the collective action view, case studies seem to be the most frequently used approach.

Inconsistent findings

Although cross-fertilization of ideas among the four perspectives is rare, both within each perspective and across perspectives, the research findings are not always convergent. We highlight three significant sets of inconsistent findings:

1. *The role of complementary products*. Although the availability of complementary products has been theorized as a key factor influencing the success of a technology standard (Suarez, 2004), the findings from empirical studies have been inconsistent. Schilling (2002) found that poor availability of complementary goods will increase

the likelihood of technological lockout. However, Stremersch and co-authors (2007) found such influence is lower than expected — by examining consumer electronics products (e.g., CD) in different historical time periods, the authors found in most markets, hardware sales drive software availability rather than the other way around.

2. *Time of adopting a standard.* Empirical studies have reported inconsistent findings regarding the relationship between the time of adopting a standard and firm survival. Suarez and Utterback (1995) found that firms entering the market before the emergence of a standard (dominant design) will have high survival chance than those entering the market after. Christensen and co-authors (1998) suggested that higher survival chance for firms is associated with a relatively short time-window. However, Tegarden and co-authors (1999) found that even for firms entering the market after a standard has emerged, firms may have high survival chance as long as they adopt the winner standard.

3. *Likelihood of winner-take-all*. The research on network effects has found that competition between incompatible technologies leads to the "winner-take-all" outcome (Arthur, 1996). However, Lee and co-authors (Lee et al., 2006) suggested in some interaction networks, customers influenced by their acquaintances may adopt a lagging technology even when a lead technology has built a large installed base, which prevents winner-take-all to occur. Anderson and Tushman (1990) also suggested that single standard that takes all market is more likely to happen in market with low appropriability regimes.

These contradictory findings cry out for resolution and may also be framed as opportunities of further research.

Future Directions

Flowing from our discussion above, the standards literature should encourage integrative studies or studies that incorporate multiple perspectives. However, given the complexity of this phenomenon, opportunities also exist for scholarship confined to a single perspective. In what follows, we outline both opportunities.

Research opportunities through theoretical and empirical integration

Given the complexity, integrative models on technology standards are especially useful. We organize our discussion along three lines: 1) Significant boundary conditions as moderators; 2) Integration among the four perspectives; and 3) Persistent debates. We provides a summary of research opportunities in Table 3.

Significant Boundary Conditions as Moderators

Our analysis of the literature suggests two major boundary conditions that limit the generalizability of the findings, boundary conditions that are left implicit and hence not adequately recognized in the literature: 1) Complexity of the technological system[15] and 2) the influence of the institutional environment.

Technological complexity. Although, as we summarized earlier, some theorists have articulated the concept of levels of technological complexity (Bettis & Hitt, 1995), their insights are rarely carried over into the theoretical reasoning and empirical works under the four perspectives. Cumulatively in this literature, the search has been for conclusions tacitly assumed to hold across levels of complexity. For example the process models of punctuated equilibrium discussed in the natural selection view were built up from the experience of simple products (Anderson & Tushman, 1990); these models may not describe the process of change in complex technological systems, where collective action may be necessary to arrive at standards. Similarly, the type of drivers of standards, strategies, systems and structures may vary across levels of technological complexity.

Influence of institutional environment. Although the dominant locale for data in the empirical literature has been the United States, some studies have looked at standards phenomenon in Europe (e.g., France, Germany, Great Britain, Italy, Scandinavia (Funk, 2003; Funk & Methe, 2001)) and Asia (e.g. Japan (Cottrell, 1994)). Although we are

[15] We thank an anonymous reviewer for suggesting this possibility.

heartened by the presence of evidence from different nations, the differences in institutional environments among nations have not been a preoccupation in the studies, making it difficult to compare findings from different nations. Further, many industries are witnessing the emergence of global standards that transcend specific institutional environments. Global evolution of standards has yet to receive significant attention in the literature.

Both these boundary conditions may be viewed as moderators that limit the generalizability of findings. Indeed, one necessary pathway to integration is development of "mid range theories" *(Hitt, Hoskisson, & Ireland, 1994)* of standards phenomenon for different levels of technological complexity and for different of institutional environments.

Integration among the four perspectives

A second line of integration is to develop additive, moderated and mediated models employing the various factors identified in Figures 8 to 11, thereby taking advantage of the developments in related perspectives to provide greater explanatory power to dependent variables of interest. Astley and Van de Ven's (1983) pair-wise approach to resolve the central debates among the central perspectives generates six pathways to build these large scale contingency models. In our discussion of studies invoking multiple perspectives, we have witnessed three attempts to this pathway to integration (e.g., Suarez, 2004; Utterback & Suárez, 1993; Waguespack & Fleming, 2009). We may suggest three more major directions to advance the standards literature:

1. Research may integrate the strategic choice and system-structural views to examine how complementors will react to the "ecosystem" controlled by technological leaders.

Technological leaders normally coordinate co-specialization within the technological regimes by facilitating standards (Teece, 2007). The success of these technological leaders, such as Intel and Microsoft, often depends not only on their own strategic actions but also on the actions of various complementors. Since leaders tend to strategically control the operations of the complementors, the way the complementors respond to the “system” would depend on the actions of the leader. At the same time, the leading position of a given technological leader can be unstable depending on various factors such as technological change, entry of competition designs, and the leader’s technology strategy. From a competitive dynamics point of view, for example, we may explore how the competitive moves of the leader in the combat against its rivals would drive the competitive moves of the complementors.

2. The collective-action and natural selection views may be combined to examine the patterns of cooperation among firms from a longitudinal perspective. Navis and Glynn’s (2010) study revealed that as a technological field becomes mature, the interaction between firms changes from collective efforts to legitimate the new technology to competition by way of differentiation. Indeed, many technology standards grow out of emerging fields whereby this type of change is likely. However, the extant standards literature has been limited in this regard. Future research may examine how firms' collective actions change along the path of technological evolution. Longitudinal research designs will be particularly useful to address this research gap.

3. Finally, it is also useful to advance the system-structural logics in light of collective-action models. The extant literature in the system-structural view has typically treated firms as individual agents who respond to the dynamics of the system (sometimes using environment as the contingency). Yet firms in standard-based competition rarely compete on individual bases. Instead, collective action is an essential nature of this competition (Suarez, 2004). Firms' reaction to the system, therefore, may depend largely on their interactions with other firms.

Persistent debates

Astley and Van de Ven (Astley & Van de Ven, 1983) articulated key differences in assumptions among the four perspectives, and our analysis of the standards literature has revealed the differing concepts, and logic structures among them in the four perspectives. Although it is possible that these differences reflect differences in the problems being addressed by the researchers, Astley and van de Ven (Astley & Van de Ven, 1983) suggest that some differences are ontological, and may persist. In the standards literature, we suspect the differences along the deterministic - voluntaristic dimension may be the most difficult to reconcile. For example, it is convenient to attribute *a priori* voluntaristic behavior to standard setting firms and deterministic behavior to those firms that are adapting to standards. However, from a voluntaristic perspective both may see as the willful decision of the firms: some firms *proactively* decide they will adapt to standards instead of creating them. A deterministic orientation may lead others to different conclusions. These differences are largely irreconcilable within empirical and theoretical domains. Integration around these assumptions is less likely to be achieved by empirical or theoretical means; rather creation of forums for debate and dialogue may be the appropriate response to these tensions (Narayanan & Zane, 2010).

Please insert Table 3 around here

Research opportunities within each perspective

Although our primary emphasis is on the need for integrative studies, we should also acknowledge that opportunities exist for research within single perspectives. We summarize some of the key opportunities along the four perspectives:

1. *Natural selection view.* Research based on the natural selection view may benefit from a further investigation into the post-standard era. In some industries (e.g., IT sectors), the cost to adopt a new technology can be very low (e.g., free software). Thus, consumers may use several technologies at the same time (multi-homing) and constantly switch back and forth between different technologies. Due to the increase in technological uncertainty, the standard-based competition in these industries may continue to be intense even after a standard has emerged (Eisenmann et al., 2006).The current punctuated equilibrium models have yet to incorporate these dynamics. A useful approach is to incorporate the network economics literature on two-sided markets (e.g., Armstrong, 2006). This literature provides important insights on the structural characteristics of network markets and the economic rationale for the rise of network effects.

2. *System-structural view.* Technological leaders controlling standards often sponsor new ventures whose products serve as complements to their key technologies. The survival of such new ventures depends largely on the “system” (normally the

technological regime) in which they operate. The extant literature has primarily tied these firms' survival to their technology strategy in the face of technology standards (e.g., Suarez & Utterback, 1995). However, the new ventures' interaction with the "system" goes beyond the technological domain to include issues such as legitimation (Navis & Glynn), equity investment (Annabelle & Cusumano, 2002), knowledge acquisition (Dushnitsky & Shaver, 2009), and misappropriation (Katila, Rosenberger, & Eisenhardt, 2008). Incorporation of the new venture literature would enhance our understanding of firms' reactions to the environmental changes in standardization processes.

1. *Strategic choice view*. Future research based on the strategic choice view may further investigate how firms' strategies shape industrial standards. One useful approach is to incorporate the action-response perspective (Chen, 1996)from the competitive dynamics research. Since firms' competitive moves constitute the basic elements of inter-firm rivalry (Chen, 1996), revealing how firms' competitive moves in the standards battle influence industrial standards and/or improve firm performance may help extend the understanding of technology standards. Recently, competitive dynamics researchers have begun to address the 'co-opetition' phenomenon (Ketchen Jr., Hult, & Slater, 2007), which is another key issue in the standards battle (Suarez, 2004). Strategic choice research also needs to use a longitudinal perspective to examine the standard-setting firms. We especially need to know more about the period following the emergence of a standard. The competition in post-standard phase is often intense among firms conforming to the same dominant technology (Gallagher & Park, 2002; Suarez, 2004). For instance, Lotus has established a standard, but why did the firm fail to establish sustained competitive advantage based on its successful Lotus-1-2-3? Similarly, IBM PC has emerged as the standard, however, why IBM failed to sustain its competitive advantage over the IBM PC clones? Therefore, it is useful to design longitudinal studies to investigate these phenomena. In addition, research based on the natural selection perspective should shed light on the proactive roles of some entrepreneurial ventures in the formulation and retention of technology standards (e.g., Microsoft, Oracle). Methodologically, the strategic choice research on technology standards should design large sample empirical studies to test the theoretical models.

2. *Collective-action view*. The collective-action perspective has to date focused primarily on empirical description and could benefit from explicit theoretical frameworks (or grounded theory works). We offer two approaches that may be worthy of consideration: a social action model of institutional innovation by Hargrave and Van De Ven (2006) and Olson's (Olson, 1971) logic of collective action. The social action model focuses on institutional change, but is built with a keen understanding of technological change. The model invokes four key concepts—framing contests, construction of networks, enactment of institutional arrangements, and collective action processes, all of which are germane to technology standards. By contrast, Olson's logic of collective action is anchored in the economics of collective action and may offer a window into the standard-based competition that incorporates the role of the government and interest groups, both of which may be significant players in the competition for technology standards. Hargrave and Van De Ven (2006) and Olson (1971) both offer macro voluntaristic perspectives but work with different assumptions. Taken together, they may offer different theoretical windows into standard-based competition at the collective level.

Table 4 displays the key research opportunities within each perspective.

Managerial Implications

This paper has several implications for managerial practice. Notably, it suggests that firms operating in science and technology intensive industries need to strategize for the emergence of technology standards, even before stable industries are formed. Competition for standards is more volatile than in stable industries, and sometimes culminates in a winner-take-all outcome, forcing the exit of firms that lose the standards battle. This competition is often characterized by network effects (Saloner & Shepard, 1995; Srinivasan et al., 2006; Suarez, 2004), entry of start-ups with new technologies (Anderson & Tushman, 1990; Zahra & Bogner, 2000), and the influence of complementors (Suarez, 2004; Teece, 2007) and others in institutional fields (Garud et al., 2002; Maguire et al., 2004).

During the competition for technology-based standards, the level of uncertainty experienced by firms is likely to be higher than during the era of incremental change and some suggested that speed of change is also significantly higher (Christensen et al., 1998).This era thus demands significant vigilance and agility on the part of participating firms. Firms need to continually scan and monitor their environments to learn the developments in the product market sector as well as the relevant technical and institutional sectors. They also need to be agile in their responses to their competitors. Organizational learning (Schilling, 2002) is a prerequisite to survival in these environments, both in product design, technology, and in a firms' strategy.

Engagement in the competition for standards requires firms to properly device their strategic position in their competitive landscape. Indeed, the competitive engagement surrounding technology standards often occurs at the system level, or community level, rather than between individual firms. The potential technological dominance of a technological community and the increasingly important role of network effects in this competition, due to interconnectivity and complementary products, require strategic managers to carefully design their interactions with various complementors and other supporting agents in the ecosystem. The work of Annabelle and Cusumano (2002) has clearly shown how two giants in the computer industry, Intel and Microsoft, have gained industrial leadership through a “platform strategy” to facilitate extensive coordination and innovation in the technological community.

In contrast to technology leaders, a key issue facing follower firms in the standardization processes is the timing of their entry into the technological field (Christensen et al., 1998; Suarez & Utterback, 1995; Tegarden et al., 1999). These firms are confronted with the challenge of predicting the future standards in the technological field — a task which is extremely difficult due to the technological and competitive uncertainty in the process of technology change. Entry before the emergence of a standard represents early mover advantages; however, it is also associated with the threat of being locked out (Schilling, 2002). Some useful tactics to address this volatility include the real option logic, multi-homing strategy, stage investment models and managerial flexibility (Eisenmann et al., 2006; Kauffman & Li, 2005; McGrath, 1997; Tegarden et al., 1999).

Collective action represents another decisive driver of standardization and innovation in technology intensive industries. Open source, co-specialization, licensing and cross-licensing, and compatibility are important issues managers must consider in strategy formulation. As Suarez (2004) has suggested, few technologies today can work in isolation and some form of collaboration with other technologies is usually required to advance a sustained competitive advantage. Nevertheless, firms' participation in collective action substantially reduces resource heterogeneity in the industry and therefore may culminate in intensified competition between technological clones, particularly after a standard has emerged and the industry has been stabilized. The techniques to manage this paradox constitute an ongoing topic among managers and in academia.

This period of competition for technology standards is also important for firms not involved in this competition as they signal potential disruptive technologies. The degree to which a technology is disruptive depends on the frame of reference, and whether a "new technology" can be detected early enough. Adequate responses can be crafted either through adoption of the new technology or through strategic action. Attention to this era of competition may yield valuable lead-time for firms in order to prevent subsequent surprises.

Summary and Conclusion

Over the past several decades, a growing body of literature has examined technology standards. These studies have adopted different perspectives, and this has partly caused fragmentation and lack of integration within the literature. Broadly, some have examined the evolution of the environmental context or macro level phenomenon whereas others have used firm as the unit of analysis. Similarly some have adopted a deterministic orientation and others have been interested in a voluntaristic orientation. Our analysis suggests the unevenness of development of literature, with collective-action and strategic choice perspectives, both particularly relevant to managerial action, being underrepresented in this literature. Indeed, studies that address collective level actions have suffered from a lack of theoretical grounding. The development of natural selection and system-structural perspectives is partly due to the availability of economic and organization theories from the 1980s; economic concepts such as two sided markets or ecological and institutional theories are yet to inspire studies in these perspectives.

Our major observation is that some researchers have invoked multiple perspectives, but these have been limited in number. Thus although much has already been accomplished, many promising opportunities lie ahead. For future research in this domain to be cumulative and impactful in guiding scholarship and managerial action, there is a need to incorporate multiple perspectives. In the future, integrative studies should move to the center stage of attention.

CHAPTER THREE: DOMINANT DESIGNS AND NEW FIRM SURVIVAL

Introduction

Every firm faces challenges as a new venture at one point and its success in the early corporate lineage depends substantially on its ability to develop the *fit* between its strategy and the industry in which it competes (Fan, 2010; Geroski et al., 2010). In the attempt at understanding these dynamics, scholars incorporated various academic perspectives to theorize the linkages between new firms' competitive environment, strategy and performance (Fan, 2010; Hannan & Freeman, 1988; Romanelli, 1989). One research stream has particularly focused on the success of new firms in the course of technological evolution (Kim & Kogut, 1996; Zahra, 1996; Zahra & Bogner, 2000). Scholars suggested that firm performance in the technology industry is a function of the firm's response to technology change, particularly, in the process in which the dominance of a single technology or design is established in a product class (Christensen et al., 1998; Mitchell, 1991; Soh, 2010; Suarez & Utterback, 1995; Tegarden et al., 1999; Tushman & Anderson, 1986).

Such a dominant technology, or a de facto standard, represents the industry-wide agreed-upon technical logic for product design and interconnectivity (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Soh, 2010). While the emergence of a de facto standard rests in the form of technical design, the impact of such an event is not merely a technological issue. Researchers have pointed out that the establishment of a de facto standard defines key facets of emerging social-economic institutions, whereby the winning design dictates 'rules of engagement' and collective benefits of various economic agents (Garud et al., 2002; Garud & Kumaraswamy, 1993; Hargadon &

Douglas, 2001). In effect, once a de facto standard begins to emerge, it not only gains mass adoption in the technological community based on its design, but also tends to lock out all other technological communities pursuing alternative designs, leading to a situation known as winner-take-all (Anderson & Tushman, 1990; Arthur, 1989; Schilling, 2002; Suarez, 2004). However, due to technological variation and competition, the emergence of a de facto standard is a highly uncertain process (Anderson & Tushman, 1990; Christensen et al., 1998; Suarez & Utterback, 1995; Tegarden et al., 1999). Accordingly, the firm's involvement in standard-based competition represents both an important opportunity to establish its core competence and destroy that of competitors, and a substantial risk of being technologically locked out if the design the firm sponsors turns out not able to accomplish technological dominance (Anderson & Tushman, 1990; Schilling, 2002).

To date, the focal point of empirical studies on firms' engagement in standard-based competition has been on firms' adaptation in the face of de facto standards (e.g. Christensen et al., 1998; Suarez & Utterback, 1995). But firms' strategy in this competition is not merely a matter of adaptation. Several researchers suggested that firms with technical capabilities to create original designs are often strongly committed to establishing de facto standards (Cusumano & Gawer, 2002; Garud et al., 2002; Khazam & Mowery, 1994; Suarez, 2004; Wade, 1996; Waguespack & Fleming, 2009). In the innovation literature, these firms are referred to alternatively under such labels as 'institutional entrepreneurs' (Garud et al., 2002; Hargadon & Douglas, 2001; Maguire et al., 2004) or 'platform leaders' (Adner & Kapoor, 2009; Cusumano & Gawer, 2002).

Creating de facto standards is a particularly meaningful strategy for new ventures whose success depends on the ability to launch 'creative destruction' (Schumpeter, 1934a, 1950) — by initiating technology change and thus new standards, new firms can not only destroy the competence of established competitors but also become a new generation of de facto industrial leaders (e.g., Microsoft and Adobe Systems). Yet this standard-based entrepreneurship is a risky business (Hargadon & Douglas, 2001). In particular, cases such as Lotus Development and Netscape indicate that even for firms who have accomplished technological dominance at one point of time, the risk factors from the technological field or poorly designed competitive strategy may completely dethrone their leadership, forcing these once glorious organizations to exit from the market. These observations lead to our research question: How will technological evolution and firm strategy influence the likelihood to exit of de novo ventures that compete by creating original designs? In the effort to provide an answer to this unaddressed issue, we draw from various theories and develop five hypotheses to conceptualize the links between the competitive environment, competitive actions and the likelihood to exit of design-based entrepreneurial ventures. We find strong empirical support for our theoretical framework based on panel data of 188 design-based entrepreneurial ventures in the period from 1980 through 2006.

Theory development

Innovation theorists conceptualize technological evolution in a product class as a cyclical model of punctuated equilibria (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Benner & Tushman, 2003; 1999; Romanelli & Tushman, 1994). This theory argues that technology change begins with a technological breakthrough, or a discontinuity, that introduces sharp improvements over existing technologies. Following a technological discontinuity is the ‘era of ferment’ in which several designs in the same product class compete fiercely to define the de facto standard (Anderson & Tushman, 1990; Benner & Tushman, 2003; Utterback & Abernathy, 1975). Since each design represents a potential technological trajectory in which various technological agents are involved, the design-based competition can be viewed as a competition between technological communities (Wade, 1995, 1996) or technological ecosystems (Adner & Kapoor, 2009; Teece, 2007), in which developers of original designs serve as central players. The design-based competition often, but not always, leads to the emergence of a de facto standard in the product class — a watershed event which changes the locus of competition in the technological domain from the competition between alternative designs to the maximization of profitability based on a winning design (Anderson & Tushman, 1990). The stability of this ‘era of retention’ is uncertain, however, depending substantially on the extent to which the de facto standard can reduce technological variation in the industry — in fact, such variation can occur whenever a new design is introduced, whether it is discontinuous or incremental (Wade, 1995, 1996).

For new ventures that are technologically capable, competing by original designs to initiate technology change represents an important strategy to destroy the competence of established technology leaders (Anderson & Tushman, 1990; Jones, 2003; Wade, 1996). However, the success (or exit) of such ‘design-based entrepreneurs’ is subject to two major risks from the industry. The first is technological variation, namely, the competition between alternative designs (Anderson & Tushman, 1990; Srinivasan et al., 2006). There are two reasons for technological variation to occur. First, when a new technological concept is introduced in a product class, there is often more than one design to implement the new technological concept — these alternative designs will compete to decide which one should be the standard expression of products in the product class (Wade, 1995, 1996). Second, firms sponsoring previous designs will defend their market positions by revising the old designs or introducing competence-enhancing designs (Anderson & Tushman, 1990; Shapiro & Varian, 1999a).

The design-based competition is often fierce; in the literature, researchers refer to this competition using such terms as ‘standards war’ (Shapiro & Varian, 1999a), ‘dominance battle’ (Suarez, 2004), ‘technology race’ (Lerner, 1997) or ‘systems competition’ (Hagedoorn et al., 2001; Katz & Shapiro, 1994). The outcome of design-based competition is uncertain. Sometimes the competition leads to winner-take-all, whereby one design captures the whole market; or, the market may alternate as one design achieves temporary dominance and is then replaced by another design; or, several designs may coexist in long periods of time with no one being selected to dominate the market absolutely (Anderson & Tushman, 1990; Arthur, 1989; Auriol & Benaim, 2000; Hargadon & Douglas, 2001; Shapiro & Varian, 1999a; Suarez, 2004; Windrum & Birchenhall, 2005; Witt, 1997).

The second risk facing design-based entrepreneurs is the industry’s selection of de facto standards. Once a design becomes the standard, it will decrease technical uncertainty in the product class and kick off the increasing returns mechanism to generate economies of scale and co-specialization with various periphery producers (Teece, 2007; Wade, 1995, 1996). Schilling (1998) summarizes two effects of the increasing returns mechanism: (1) a widely used design will be rapidly improved through learning-by-doing; and (2) network externalities are said to arise as the value of a design depends on the size of its installed base (Farrell & Saloner, 1985; Katz & Shapiro, 1986, 1992; Schilling, 2002; Sheremata, 2004; Suarez, 2004). Furthermore, from an institutional perspective, Hargadon and Douglas (2001) and Garud et al. (2002) argue that the emergence of a de facto standard is not only a significant event in the technical domain, but also a social-economic signal which *legitimates* the winning design and *de-legitimates* all other designs. Yet it should be noted that, for a particular design-based entrepreneur, the emergence of a de facto standard represents a twofold possibility. On the one hand, the entrepreneur's design may emerge as the de facto standard; on the other hand, a competing design may emerge as the de facto standard — these different outcomes can have very different performance implications for the focal design-based entrepreneur (Anderson & Tushman, 1990; McGrath et al., 1992; Murmann & Frenken, 2006; Srinivasan et al., 2006).

In addition to risk factors from the industry, Utterback and Suárez (1993) further consider the firm's mistakes in undertaking competitive practices along with technological evolution as a major source for organizational failure. Suarez (2004) specifically points out that, to be successful, a design-based firm must develop the ability to manage a *repertoire* of competitive actions, such as those of entry timing, pricing, licensing, partnerships, marketing and others. While the innovation literature traditionally examines how certain types of actions may influence the firm's performance in design-based competition (Christensen et al., 1998; Suarez, 2004; Suarez & Utterback, 1995), this perspective might be supplemented by an overview of the general characteristics of the firm' competitive repertoire — the approach usually used in competitive dynamics research (Ferrier, 2001; Ferrier, Smith, & Grimm, 1999; Miller & Chen, 1994, 1996). In this paper, we develop a perspective to bridge these two relatively disconnected bodies of literature. On the one hand, we follow the competitive dynamics researchers to propose a direct link between a design-based entrepreneur's likelihood to exit and its *concentration in competitive actions,* defined as the degree to which a design-based entrepreneur tends to focus on certain types of competitive actions (Ferrier et al., 1999; Miller & Chen, 1996). On the other hand, we argue that the strength of this relationship may be influenced by the factors in the process of technological evolution. A summary of these considerations leads to our integrative framework as illustrated in Figure 12.

Please insert Figure 12 around here

Technological Variation

To assess the effects of technological variation, we examine how the total number of competing designs in a product class will influence the success (or exit) of a focal design-based entrepreneur. Rooted in institutional theory, Hannan and Freeman's (1988; 1986) density-dependence theory conceptualizes two competing mechanisms that link the number of competitors in the industry to the success of a focal firm. The first is legitimation. Accordingly to Hannan and Freeman, when a market is first developed, increases in the number of firms offering similar products /services will encourage more entrants into the industry, reduce barriers to capital acquisition, and signal entrepreneurs of the business opportunities (Wade, 1996). Essentially, these mechanisms will result in increased legitimacy as customers and capital market increasingly accept the new products or services as 'taken-for-granted', which in turn enhances firms' success. The other mechanism that develops in parallel is competition. Overtime, increases in the number of firms will intensify competition for resources and customers, leading to increased difficulty for firms to generate profitability. At some point, the effect of competition will outpace the effect of legitimacy. Thus, Hannan and Freeman propose an inverted U-shaped relationship between the total number of competitors in an industry and firms' survival chance.

Drawing on Hannan and Freeman's theory, Wade (1995, 1996) suggests that legitimation and competition represent two competing drivers in design-based competition too. On the one hand, original designs create new product classes and new meanings in the technological field (Garud et al., 2010; Verganti, 2009); in this process, the need for legitimacy highlights the value of having more designs in the same product class (Navis & Glynn). Wade (1996) specifically argues that legitimation works in two aspects. First, customers often have high switching costs when they decide to invest in a particular design. To avoid 'being strangled', they are very cautious in evaluating the potential of each design and are more likely to invest in designs that are 'taken-for-granted' (Arthur, 1989; Farrell & Klemperer, 2006; Liebowitz & Margolis, 1995). Second, the technical specifications of new designs are often poorly understood and functionalities are unstable (Anderson & Tushman, 1990); more similar designs in the market will help enhance the 'taken-for-grantedness' of the new technology and justify the values it produces (Wade, 1996). Hargadon and Douglas (2001) find that when firms introduce new designs to displace old designs, it is very important for the new designs to exploit the institutions established by old designs; immediate replacement of old designs may actually lead to poor diffusion of new designs. Following a similar logic, Garud and colleagues (2002) further suggest that a design-based entrepreneur is in fact an institutional entrepreneur whose success depends substantially on the ability to extend the institutional space by involving more players, even competitors, through technological openness. In some cases, the seek for legitimacy may encourage firms sponsoring competing designs to develop compatibility across designs — these collective actions encourage co-existence of multiple designs in the same product class (Annabelle & Cusumano, 2002; Cusumano & Gawer, 2002; Dahlander & Gann, 2010; West, 2003).

On the other hand, different designs compete fiercely for technological leadership and market share (Arthur, 1989; Arthur, 1996; Auriol & Benaim, 2000; Farrell & Klemperer, 2006; Liebowitz & Margolis, 1995; Majumdar & Venkataraman, 1998; Witt, 1997). The competitive dynamics between designs has two major characteristics. First, design-based competition normally involves only a very limited number of designs; however, each design represents a technological trajectory and is supported by a large number of periphery complementors (Teece, 2007). Second, due to network effects and learning-by-doing, the dominance of a single design is self-reinforcing (Schilling, 1998, 2002); in effect, the success of one design often results in sharply decreased market shares for all other designs (Gallagher, 2007; Katz & Shapiro, 1994; Saloner & Shepard, 1995; Srinivasan et al., 2006; Stremersch et al., 2007). The rise of JVC's VHS, for example, reduced the market share of its major competitor, Sony's Betamax, to minimum (Cusumano et al., 1992). From a competitive point of view, a single design here represents no less competitive threat than, say, ten designs — the competitive threat imposed by additional designs is relatively marginal. Thus, the entry of the very first few designs will impose significant threat against a focal design-based entrepreneur but offer limited legitimation effect. As the total number of competing designs continues to increase, the legitimation effect becomes stronger while the increase in competitive threat demonstrates diminishing return. Eventually, legitimation will exert stronger influence than competition. These arguments lead to our first hypothesis:

> *Hypothesis 1: The total number of competing designs will have a curvilinear (Inverted U-Shaped) relationship with a focal design-based entrepreneur's likelihood to exit. Specifically, the first few number of competing designs will increase a focal design-based entrepreneur's likelihood to exit; however, after the total number of competing designs reaches a certain point, additional number of competing designs will decrease a focal design-based entrepreneur's likelihood to exit.*

The Emergence of de facto Standards

We follow Anderson and Tushman (1990) to define a de facto standard as a single technological design that establishes dominance in a product class (Abernathy & Utterback, 1978; Anderson et al., 2005; Benner & Tushman, 2003; Soh, 2009). A product class may not select any design as the de facto standard in long periods. Once a design becomes the de facto standard, however, it exerts profound influence on organizations (Anderson & Tushman, 1990; Funk, 2004; Soh, 2009; Srinivasan et al., 2006; Weiss & Birnbaum, 1989). First, future innovation will be regulated to a technological order based on the winning design (Abernathy & Utterback, 1978; Sahal, 1981; Utterback & Abernathy, 1975). As technical uncertainty declines substantially in the product class, economies of scale and incremental improvements to enhance the winning design become the focus of the technological community (Anderson & Tushman, 1990; Teece, 2007; Wade, 1995, 1996). The rise of a standard also signals the de facto leadership of the winning design, forcing producers of various complementary products to obey the 'rules of engagement' dictated by the winner (Christensen et al., 1998; Garud et al., 2002;

Murmann & Frenken, 2006; Soh, 2009; Suarez & Utterback, 1995; Tegarden et al., 1999). Marketwise, large volumes of sales and high availability of periphery products send signals to customers indicating the value of the design, triggering bandwagon in adoption (Wade, 1996). Additionally, once a design establishes absolute market dominance, all other designs will have to compete in a small market space, which increases hazards for their sponsors. Absolute dominance in market share also largely brings down the production costs for the winner, putting all other designs in a price disadvantage (Farrell & Saloner, 1985, 1986; Saloner & Shepard, 1995).

For a focal design-based entrepreneur, the emergence of a de facto standard represents a twofold possibility. First, a competing design may become the de facto standard. This event announces the failure of the focal entrepreneur in design-based competition. While the design-based entrepreneur may continue to market its own design, customers and producers of periphery products are more interested in supporting the winning design, making it very difficult for the design-based entrepreneur to diffuse its technology. The continuous loss of market share may eventually force the entrepreneur to exit. Thus, we hypothesize:

Hypothesis 2: The emergence of a competing design as the de facto standard will increase a focal design-based entrepreneur's likelihood to exit.

The second possibility is that a design-based entrepreneur may establish a de facto standard in the product class. Success in the dominance battle highlights the entrepreneur as the de facto technological leader (Cusumano & Gawer, 2002; Teece, 2007), allowing the new venture to exploit such advantages as extensive coordination in the industry, complementary products, learning curve, bandwagon effects and institutionalization

(Aldrich & Fiol, 1994; Garud et al., 2002; Hardy & Maguire, 2008; Schilling, 1998, 2002; Suarez, 2004, 2005). In spite of these benefits, the ability to predict the organizational success of the de novo technological leader is still an uncertain process. First, the emergence of new technologies represents a constant threat against the design-based entrepreneur — in fact, each slightly improved design could constitute substantial risk to dethrone the leading position of the new venture (Wade, 1995, 1996). In addition, design-based entrepreneurs often use unusual strategies to win the dominance battle, such as those of technological openness, cross-licensing, and collaborative innovation (Garud et al., 2002; Garud & Kumaraswamy, 1993). These strategies, while useful in competing against other designs, may at the same time foster technological imitation and sometimes create technological clones in the same product class, giving rise to head-to-head competition in a later stage. For instance, to establish a de facto standard in the personal computer market, IBM allowed other computer manufacturers to access its core technology; the competitors thus created later competed fiercely with IBM and eventually drove the company out of the market. Furthermore, researchers suggest that after a design-based entrepreneur establishes a de facto standard, the changes in competitive emphasis requires the firm to substantially adjust its competitive practices; the firms' inability to accomplish this transition will be a major source for organizational failure (Utterback & Suárez, 1993).

In spite of these challenges, design-based entrepreneurs controlling de facto standards do have certain advantages in rivaling against other designs. The self-reinforcing installed base, for instance, allows the entrepreneur to offset the competitive advantage of more innovated designs (Katz & Shapiro, 1985, 1992). Technological dominance also reduces the motivation of other design-based firms to undertake aggressive actions. From a competitive point of view, firms' decision to undertake competitive attacks largely depends on the expected payoffs (Besen & Farrell, 1994; Chen, 1996; Chen & Miller, 1994; Chen, Smith, & Grimm, 1992; Shapiro & Varian, 1999a, b; Young, Smith, Grimm, & Simon, 2000). If a competitive action is likely to generate threatening retaliation, the firm tends to withdraw the action (Chen, 1996). Mirroring this logic, Shapiro and Varian (1999a) suggest that designs that fail to become de facto standards should seek truce rather than competition with the de facto standard—for example, these designs may develop compatibility with the de facto standard. For firms controlling standards, the collective action of this kind not only reduces the threat of technological variation but also will further enhance the legitimacy of the its own technology. Thus, we argue that the relationship between technological variation and the exit of a design-based entrepreneur will demonstrate a different pattern if the technology of the design-based entrepreneur becomes the de facto standard. Specifically, after a design-based entrepreneur establishes a standard, (1) the rate of increase in its likelihood to exit due to competitive threat will be lower; and (2) the rate of decrease in its likelihood to exit due to legitimation will be faster. A summary of these arguments leads to the following hypothesis:

> *Hypothesis 3: The emergence of a focal entrepreneur's design as the de facto standard will moderate the relationship between the total number of competing designs in the same product category and the focal design-based entrepreneur's likelihood to exit.*

Concentration in Competitive Actions

Concentration in competitive actions captures a design-based entrepreneur's strategic orientation to develop specialization in a narrow range of activities, or, to compete more generally by engaging in a broader range of activities (Ferrier et al., 1999). Schumpeter (1934b, 1950) describes the firm's competitiveness as the ability to undertake a wider range of competitive actions. Accordingly, firms' concentration in certain types of competitive actions is considered as an indicator of the firm's action simplicity (Miller & Chen, 1996), lack of resources (Ferrier et al., 1999) and/or competitive unaggressiveness (Yu et al., 2009). Miller and Chen (1996) cite Ross Ashby's (1956) 'law of requisite variety' to argue that the firm must have a comprehensive, diversified competitive repertoire to capture different customer needs; in contrast, concentrating only on certain kinds of actions carries the risk of missing important market contingencies (Miller, 1992). From a resource-based view, Ferrier (1999) suggests that the abundance of firm resources often allows the firm to launch a variety of competitive actions; in contrast, the firm's concentration in certain competitive actions may manifest resources scarcity and therefore is negatively related to its performance. In a later paper, Ferrier (2001) further introduces a game theory perspective to examine the effects of firms' concentration in competitive actions. He argues that the firm competing with diversified activities will increase the difficulty for rivals to respond; however, if the firm's competitive weapon is limited, the likelihood of response from rivals will increase, which in turn generates negative impact on firm performance.

In the literature on design-based competition, researchers have also discussed the potential danger of concentration in competitive practices. Arthur (1989; 1996) suggests that due to the increasing returns mechanism, a small lead in the installed base may enable a design to eventually capture the entire market. Accordingly, design-based entrepreneurs must pay attention to various 'insignificant events' to address the nonpredictability of this competitive war —concentrating only on certain activities may fail to address some important market contingencies and thus increase the risk of technological lock-out. Warner and colleagues (2006) suggest that a real option logic may help manage the uncertainty in design-based competition. Warner and colleagues particularly focus on design-based firms' technology strategy before the emergence of standards. According to them, it is beneficial that design-based firms invest in multiple technological areas to keep *growth options* open; in contrast, only developing specialized competence in a particular technical area may increase the risk of technological lock-out (Kauffman & Li, 2005; McGrath, 1997; Warner et al., 2006). We argue that the real option logic not only addresses a design-based entrepreneur's technology strategy but also applies to other competitive activities as well. Indeed, constant technology change and market uncertainty requires the design-based entrepreneurs to use various competitive weapons to deal with the changing competitive dynamics. As a result, concentration in competitive actions overall may have a negative influence on design-base entrepreneurs' long-term success. Thus, we hypothesize that:

> *Hypothesis 4: Overall, the degree of concentration in a design-based entrepreneur's competitive repertoire will be positively related to the design-based entrepreneur's likelihood to exit.*

Technological and market uncertainty highlights the importance of having a wider range of competitive actions; the stability in the technological market, however, may favor firms competing with specialized competitive repertoires (Miller & Chen, 1996). A watershed event in design-based competition substantially reducing market uncertainty is that the design of the entrepreneur becomes the de facto standard in the product class (Anderson & Tushman, 1990). Once a design-based entrepreneur establishes a de facto standard, practices in the technological domain will be regulated by the ‘rules of engagement’. Now, standardized operations and specialization become the focal point of competitive actions (Garud et al., 2002; Teece, 2007). Teece (2007) stresses the importance of ‘co-specialization’, arguing that firms controlling standards must concentrate on technological collaboration to gain competitive advantage in the standardization process. Utterback and Suárez (1993) suggest that successful design-based entrepreneurs will be those who manage to transform from ‘generalists’ to ‘specialists’ — firms that concentrate on a narrow range of competitive practices. A similar idea is also presented by Romanelli(1989). Thus, we hypothesize:

> *Hypothesis 5: The emergence of a design-based entrepreneur’s design as the de facto standard will weaken the positive relationship between the degree of concentration in the design-based entrepreneur’s competitive repertoire and its likelihood to exit.*

Methods

Sample

An appropriate sample to test our hypotheses required identifying new organizations that have involved in design-based competition. For this purpose, we must develop a pool of technological designs that competed to define de facto standards. Previous empirical studies on similar topics suffered a major limitation in identifying a substantial number of such technological designs: the largest sample used for hypothesis testing was developed by Srinivasan and colleagues (2006) who identified 63 office products and consumer durables. We designed our research to overcome this limitation. By talking to industrial experts and reading extensively various trade journals, we recognized that the emergence of a de facto standard is a major industrial event and will likely capture substantial attention in media. Logically, we expected that an extensive search in various media sources should allow us to identify a significant number of such design-base competitors. Having this idea in mind, we utilized a search process which involved three major steps. In Step One, we developed a thesaurus to capture the core concept of a ‘de facto standard’ — a technological design that dominates the market. After we extensively read research publications and trade journals and talked to various industrial experts, we found that the phenomenon could be referred to alternatively in the media using such terms as ‘dominant design’, ‘technology /technological standard’, ‘industry/industrial standard’, ‘standards war’, ‘dominance battle’ and/or ‘standards competition’. For an inclusive search, we included all these keywords to construct our first thesaurus (Thesaurus One).

In Step Two, we launched a search at Lexis-Nexis database using Thesaurus One, yielding more than 10,000 newspaper articles containing at least one keyword. A review of these articles uncovered a number of technological designs involved in creating de facto standards. In further investigation, however, we found that a large portion of these technologies were duplicates and some were irrelevant or ambiguous, which substantially reduced our pool to 167 technologies. We carefully examined each technology to understand which product class it belonged to using following sources: Software Taxonomy and Hardware Taxonomy developed by a leading market research company, technical descriptions offered in public sources such as newspapers, company websites and annual reports, and expert opinions. The investigation indicated that the 167 technological designs belonged to 145 product categories.

Step Three involved an additional search for 'competitors' of aforementioned technological designs using a thesaurus (Thesaurus Two) of keywords such as 'competitors', 'competing', 'compete', 'rival', 'defeat' and many others[16]. This search was necessary because it substantially adjusted the skewness towards more successful technological designs in our search. For example, in the search for technological designs competing to establish de facto standards in spreadsheet market, using Thesaurus One only uncovered two successful technological designs: 'Lotus 1-2-3' and 'Microsoft Excel'; however, using Thesaurus Two, we further identified such technological designs as 'Quattro Pro' and 'VP Planner', which were unsuccessful rivals against 'Lotus 1-2-3'. This exhaustive search enabled us to capture most of the technological designs in a given product category.

The final pool included 358 technological designs in 145 product categories. A further investigation indicated that these technological designs were sponsored by 253 organizations in which 188 were firms incorporated after 1980. We then carefully examined the products/technologies of these firms and found that standardization was the core strategy for all firms since their incorporation. Thus, this group of firms constituted an appropriate sample to test our hypotheses.

Measures

Likelihood to Exit. The analysis of organizations' exit, or failure, has been a typical approach to test firm performance from a longitudinal perspective. We defined the firm's exit as the event that the firm discontinued to operate as an independent organization. To operationalize the firm's likelihood to exit, we used event history

[16] The complete list has 32 keywords and will be provided upon request.

analysis to model firms' *hazard* for exit. We collected information about firm exits from various sources: VentureXpert, LexisNexis, Mergent and 10-k Forms. The data indicated that firms could exit from the marketplace in various forms which included bankruptcy, disbanding, merger and acquisition (M&A) (Cattani, Ferriani, Negro, & Perretti, 2008). In particular, M&As of private firms were a complex issue — for instance, Waguespack and Fleming (2009) argue that some M&As of private firms should be considered as liquidity events which indicated superior firm performance. In addition, there was also the 'living dead' phenomenon associated with new ventures (Ruhnka, Feldman, & Dean, 1992). To address this complexity, we investigated each M&A in detail to understand whether the M&A truly indicated organizational discontinuity. However, we could not find enough information to identify the post M&A performance for many private firms. Thus we separated M&As of public companies (89 firms) from those of private companies (99 firms) and then used separate models to compare the difference — similar results were reported. To deal with the 'living dead' problem, we carefully examined firms' competitive actions: The firm was considered as a 'living dead' if it no longer launched competitive actions even though the organization still existed.

Based on this information, we modeled the instantaneous hazard for exit of a design-based entrepreneur in a given year *t*, as:

$$h(t) = \lim_{\Delta t \to 0} \left(\frac{\Pr\{ t \leq T < t + \Delta t \mid T \geq t\}}{\Delta t} \right)$$

where represented the time when the observation window was closed, indicated the likelihood of that an exit would occur during the time interval from to .

Total Number of Competing Designs. The three-step search allowed us to develop listings of competing designs in each product category. We then collected information about the entry and exit of each technological design. An entry was recorded when the firm first introduced a design; the information was collected from newspapers in LexisNexis database, and then verified with other sources such as annual report, company website, information provided by other research articles or books. Exit was recorded when the firm discontinued the product line. We also recorded exit of a technology if it completely disappeared from all public sources. In addition, following Tushman and Anderson (1986), exit was also recorded when the firm discontinued operating as an independent firm. With the entry-and-exit information, we constructed yearly listings of competing designs for all product categories to operationalize total Number of Competing Designs (*Number of Competitors*).

Emergence and Time of de facto Standards. We followed the method of Srinivasan and colleagues (2006) to measure emergence and time of de facto standards. Srinivasan and colleagues' (2006) methodology involved two steps. First, two graduate students content-analyzed various archival sources to identify whether and when a technological design has become a de facto standard (dominant design). Second, the authors validated this measure by collecting market share data[17] and consulting multiple industrial experts. Srinivasan and colleagues (2006) reported high correlation (ρ =.86) between the de facto standard's emergence times measured respectively by content analysis and market share data.

[17] The criteria to decide whether and when a technology has become a de facto standard was that its market share was beyond 50 %, the same criteria used by Anderson and Tushman (1990).

We utilized the same procedure in this study. We first collected various archival information (e.g. research articles, books, trade journals, newspapers) reporting a particular technological design's involvement in standardization [18]. Two coders (one author and a Ph.D. student) separately read the articles to code whether and when a technological design has emerged as a de facto standard. The two coders unanimously coded the emergence and time of 105 technological designs as de facto standards. We then followed Srinivasan and colleagues (2006) to validate our measure. We collected market share data for each technological design; due to data unavailability, we only found market share data for 60 of the 105 technologies coded as de facto standards. We then correlated the de facto standards' emergence times identified from two methods. A correlation of .97 was reported, indicating high consistency between two measures. To further enhance our confidence, we invited several industrial experts to review the technological designs we identified as de facto standards and asked them to comment on (1) whether the technological designs should be considered as de facto standards and (2) when the technological designs, if ever, emerged as the de facto standards. Thus, we were reassured of the reliability of our measure.

We then operationalized our variables using aforementioned information. As we mentioned above, for a design-based entrepreneurial venture in year *t*, the emergence of a technological design as the de facto standard represented a twofold possibility: (1) the emergence of a focal venture's design as the de facto standard, or (2) the emergence of a competing firm's design as the de facto standard. In addition, a design-based entrepreneur

[18] We collected relevant research articles by a comprehensive literature review. We found relevant trade journals and newspapers by searching the technology's name together with keywords such as 'standard' , 'dominance', ' winning' and so on.

may establish more than one de facto standard, or compete with a number of standards in multiple product classes in a given year *t*. Thus we used the variable *Own Standard* to denote the number of de facto standards a design-based entrepreneur possessed in year *t*. We used *Competitor Standard* to denote the total number of de facto standards established by the design-based entrepreneur's competitor(s) in the product classes in year *t*. If two designs emerged as de facto standards chronologically, the first one was recorded as dethroned after the second one established de facto standard.

Concentration in Competitive Actions. To operationalize *concentration in competitive actions*, we first indentified competitive actions. A competitive action is defined as an individual move that the firm undertakes to enhance its market position (Chen, 1996; Chen & MacMillan, 1992; Chen et al., 1992; Smith, Grimm, Gannon, & Chen, 1991; Yu et al., 2009). To identify the competitive actions of design-based entrepreneurs, we collected textual data in published news articles and wires from the LexisNexis database. We limited our search to Business Wires. To establish that Business Wires was the appropriate source for our purpose, we randomly selected ten design-based entrepreneurs and searched in LexisNexis database for all news articles that had the names of the companies in their headlines. Then, we listed out the first ten outlets that had most hits in the search, whereby we found that Business Wires stood on the top of the list. Next, we randomly selected 50 news articles for each company from other outlets to see whether they were reported in Business Wires as well. A careful review of these articles revealed that more than 90 per cent of the news articles reported in other outlets were also reported by Business Wires. Thus, we were confident that Business Wires was an appropriate source to collect data for competitive actions.

Following Ferrier (1999), we focused on news headlines to identify the competitive actions. We included all news headlines from Business Wires that contained the name of a company in our sample. When the name or abbreviation of the company led to confusion, we used LexisNexis 's 'intelligent indexing' function to screen out irrelevant headlines, a technique used by Uotila and colleagues (2009). An extensive reading of these news headlines and the literature on competitive dynamics suggested that these competitive actions belonged to 13 categories: 'Introduce a new product / innovation', 'Update an existing product', 'Form product / innovation alliances', 'Form marketing based alliances', 'Merger and Acquisition', 'Open new divisions or restructure the organization', 'Involve in open source development' 'Sign licensing agreement', 'Improve distribution or customer services', 'HR action', 'Price action or Promotion', 'Undertake legal action', 'Participate in trade events'. We validated these categories by consulting several management professors and industrial experts and they agreed that these were the common most types of competitive actions in the information technology industries.

We then used a software package, *PASW Text Analytics for Survey*, to categorize the competitive actions. *PASW Text Analytics for Survey* is a software package developed by SPSS Inc. to code textual data into meaningful categories. There were several advantages of using this software. First, *PASW Text Analytics for Survey* utilized several automated linguistic techniques to enhance the reliability of the computer-aided coding. To assess its accuracy and reliability, we ask two coders to manually coded 600 headlines and then used the software to code the same news headlines; a detailed review of the coding results indicated that there was very high consistency between human and computer-aided coding (greater than 80 percent agreement). The second advantage of using computer-aided coding was that it allowed us to handle large dataset with relatively high efficiency. As the number of observations increased, the impact of a single coding mistake could be substantially reduced (Uotila et al., 2009).Accordingly, we used *PASW Text Analytics for Survey* to code our competitive actions data. The final dataset contained 32,941 competitive actions.

With the competitive actions data, we operationalized *concentration in competitive actions* using a composite measure. Following previous research (Ferrier et al., 1999; Yu et al., 2009), we first calculated the overall concentration of a design-based entrepreneur's competitive actions by estimating the extent to which a design-based entrepreneur carried out a broad range as opposed to a narrow range of competitive actions in year *t*. Using $N_{i,,j,,k}$ to denote the total number of actions a design-based entrepreneur undertook in a particular type of action *j*, we calculated the overall concentration index in year *t* as follows:

$$C_{i,t} = \sum_{j,t} (N_{i,j,t} / N_{i,t})^2$$

Miller and Chen (1996) suggest that the firm's focus on certain types of actions may also be reflected by its emphasis on the single most common type of action in year *t*. Thus we calculated the dominance index using the following formula:

$$D_{i,t} = (\max_{j} N_{i,j,t}) / N_{i,t}$$

We performed a factor analysis on the two indices and a high Cronbach's Alpha (.98) indicated the internal consistency between two indices. Thus, we took average of two scores as the final measure for concentration in competitive actions. We used one-year lag in our analysis to adjust for the effect that a company may undertake less actions in the year in which exit occurred.

Control Variables. We controlled several industry and firm level variables to rule out plausible alternative explanations. Previous research has indicated that market demand and market competition may influence the survival of new organizations (Brittain & Freeman, 1980; Romanelli, 1989). Thus, we controlled for market demand using the total sales in year *t* of all firms sharing the first two digits in SIC code with the focal design-based entrepreneur. With a similar method, we controlled for the effects of market competition using total number of firms in year *t.* At the firm level, we controlled for the size of design-based entrepreneurial ventures using the number of employees in year *t* and the effects of firm age. We used a time-varying dichotomous variable to control for the new ventures' IPO status in year *t* and noontime-varying dichotomous variable to indicate whether the venture received VC funding. Research on competitive dynamics has suggested that the overall competitive aggressiveness may influence firm performance (Ferrier et al., 1999; Yu et al., 2009). Consistent with this research, we collected yearly data to control for the firm's overall competitive aggressiveness using its total number of competitive actions in year *t-1*. Finally, we controlled for the year effects by including a dichotomous variable, Years80-89, to indicate if the design-based entrepreneurial venture was incorporated in the period between 1980-1989.

Analysis

Our dataset consisted of longitudinal observations reflecting how industrial and firm strategy changes may influence design-based entrepreneurs' likelihood to exit. To model this dynamics process, we need not only consider whether a design-based entrepreneur has exit from the market, but also when it exit, as well as the industrial conditions and its competitive strategy at the time or before the occurrence of its exit. We also need to address the challenge of censoring: while we did not observe the firm's exit in our data, it may exit right after the completion of our observation at the year 2006. These requirements made the discrete method of event history analysis the salient analytical technique. The event history analysis techniques provide alternative ways to deal with time-dependent covariates of this kind; one extensively used method includes Cox regression model (Allison, 1995, 2001; Waguespack & Fleming, 2009). Nevertheless, Allison (1995) points out that Cox regression involves quite complex data manipulation and computational procedures, and one can easily make a mistake with realizing. Alternatively, Sarkar and colleagues (2006) used the random-effects complementary models to handle a similar analysis based on unbalanced firm-year panel data, a data structure similar to ours. However, the log_log model suffers a limitation by assuming that the hazard follows a complementary log_log distribution. In view of the strengths and weaknesses of these methods, we decided to conduct parallel analyses using both models to test our hypotheses. Accordingly, the model specifications were:

$$h_i(t) = h_0(t) \times \exp\left\{\sum \beta_k \times \left[X_{i,k}(t)\right]\right\}$$

for Cox model, where $X_{i,k}(t)$ represented the value of the k^{th} variable for firm i at time t ,

$h_0(t)$ denoted the baseline hazard, and

$$-\log(1 - P_{i,t}) = \exp\left\{a_t + \sum \beta_k \times [X_{i,k}(t)]\right\}$$

For log_log model, where represented the probability that exit will occur for firm *i* at time *t.*

Results

Table 5 presents the results of our analysis predicting the relationships between industry conditions and design-based entrepreneurs' hazard for exit. In both Cox and models, a positive coefficient in the outputs indicated a positive relationship between the independent variable and hazard for exit. Model C1 and Model LL1 included only control variables. We found evidence suggesting that design-based entrepreneurs' hazard for exit was negatively related to market demand, but positively related with the total number of competitors. The firm size variable was significant and negative, indicating that larger design-based entrepreneurs have had lower hazard for exit. We also found that design-based entrepreneurs incorporated in 1980s suffered lower hazard for exit, compared with those that came into being after 1990, perhaps due to first mover advantages in the emerging IT industries. We also found several surprising results. First, we found design-based entrepreneurs' IPO status had a significant and positive relationship with its hazard for exit. In addition, our analyses reported contradictory results in terms of the relationship between firm age and hazard for exit in Cox versus Log_log models. Finally, we did not find significant relationship between design-based entrepreneurs' total competitive actions in time *t-1* and hazard for exit at time *t*.

Hypothesis 1 predicts that the total number of competing designs in the same product class will have a quadratic relationship with a design-based entrepreneur's hazard for exit in the way that the first few number of competing designs will increase a focal design-based entrepreneur's hazard for exit; after the total number of competitors reaches a certain point, additional number of competing designs will decrease a focal design-based entrepreneur's hazard for exit. If this hypothesis holds, the coefficients in the regression models for the total number of competitors should be positive and the coefficients for its square term should be negative. Model C2 and Model LL2 tested this hypothesis (see Table 5). The coefficients for the total number of competing designs were positive and significant (Cox: $\beta = .51$, $p < .001$; Log_log: $\beta = .51$, $p < .001$), and the coefficients for its square term were negative and significant (Cox: $\beta = - .05$, $p < .05$; Log_log: $\beta = - .06$, $p < .01$), providing strong support for Hypothesis 1.

Please insert Table 5 around here

Hypothesis 2 predicts that the emergence of a competing design as the de facto standard will increase a focal design-based entrepreneur's hazard for exit. We used Model C3 and Model LL3 to test this hypothesis. The coefficients for *Competitor Standard* were positive and significant (Cox: $\beta = .54$, $p < .001$; Log_log: $\beta = .71$, $p < .001$), strongly supporting our hypothesis.

Hypothesis 3 argues that the emergence of a focal entrepreneur's design as the de facto standard will moderate the relationship between the total number of competing designs in the same product category and the focal design-based entrepreneur's hazard for exit. To test this hypothesis, we constructed Cox regression Models C4, C5 and C6, and Log_log Models LL4, LL5, and LL6. In Models C4 and LL4, we included variables, *Own Standard*, *Number of Competitors* and its square term. Then we moved on to construct Model C5 and LL5, in which we included interaction term, *Own Standard* × *Number of Competitors*, to test whether *Own Standard* moderates the linear effects of total number of competitors on design-based entrepreneur's likelihood to exit. The coefficients for the interaction terms were negative but only significant for one-tailed tests (Cox: $\beta = -.18$, $p < .05$ one-tailed; Log_log: $\beta = .51$, $p < .10$ one-tailed), providing weak support for the hypothesis. We then constructed Model C6 which included two interaction terms , *Own Standard* × *Number of Competitors* and , *Own Standard* × *Number of Competitors Square*, to further test whether *Own Standard* moderates the nonlinear effects of total number of competitors on design-based entrepreneur's likelihood to exit. We found no support for this expectation.

Please insert Table 6 around here

Table 6 presents the results of our analysis predicting the relationships between the degree of a design-based entrepreneur's concentration in competitive actions and its hazard for exit. Again, we utilized Cox and models in our analysis. Models C7 and LL7 only involved control variables. In addition to the control variables in Models C1 and LL1, we controlled for the effects of total number of competing designs due to the reason that this variable might affect the effectiveness of design-based entrepreneurs' competitive actions. Models C8 and LL8 tested Hypothesis 4 which predicts that a higher degree of concentration in competitive actions of a design-based entrepreneur will be positively related to its hazard for exit. After we added the two variables, *Concentration* and *Own Standard*, into the model, we found that the coefficient for *Concentration* was positive and significant in both models, suggesting that as *Concentration* increased, the design-based entrepreneurs had higher hazard for exit. Thus, we Hypothesis 4 was supported.

We then added the interaction term *Concentration* × *Own Standard* in Models C9 and LL9, respectively, to test the moderation effect as predicted by Hypothesis 5. Accordingly to Hypothesis 5, after the emergence of a design-based entrepreneur's design as the de facto standard, the negative relationship between a design-based entrepreneur's concentration in competitive actions and its hazard for exit will become weaker. The results in Model C9 and LL9 both showed that the interaction term, *Concentration* × *Own Standard* , was significant (-1.50, $p < .05$; -1.57, $p < .05$). By a partial differentiation of Model C9 with respect to *Concentration*, we got

$$\partial\, h_i(t) / \partial\, Concentration = 1.42 - 1.50 \times Own\ Standard$$

The Equation indicated that when a design-based entrepreneur has not yet established a de facto standard (*Own Standard* < 1), *Concentration* will be positively related to the hazard to exit; however, after the design-based entrepreneur established a de facto standard, this effect will be largely offset — in this situation, *Concentration* will be negatively related to the hazard for exit. Similar results were reported in Model LL11. Therefore, our Hypothesis 5 was supported.

Discussion

Overall, the results provided support for our theoretical framework. The first set of results indicated that the two risk factors from the industry, the total number of competing designs in the product class and the emergence of a de facto standard, had strong effects on design-based entrepreneurs' hazard for exit. Consistent with our first hypothesis, we found a curvilinear (inverted U-shaped) relationship between the total number of competing designs and the design-based entrepreneurs' likelihood to exit. We also found that when a competing design became the de facto standard, the focal design-based entrepreneur experienced higher hazard for exit. Additionally, we found support for the expectation that the emergence of a focal entrepreneur's design as the de facto standard will moderate the relationship between the total number of competing designs and the design-based entrepreneur's hazard for exit.

Our second set of results indicated that overall, design-based entrepreneurs' concentration in competitive actions was associated with higher hazard for exit. This finding was consistent with the competitive dynamics literature whereby concentration in competitive actions is considered as an indicator of competitive simplicity (Ferrier et al., 1999; Miller & Chen, 1996; Yu et al., 2009). However, we found that the effectiveness of this strategy depended substantially on the design-based entrepreneurs' status quo in the design-based competition — as the entrepreneur's design became the de facto standard, the positive relationship between concentration in competitive repertoire and hazard for exit turned negative. Our findings echoed Utterback and Suárez (1993) who argue that successful design-based firms would be those who transform from 'generalists' to 'specialists'.

Our research is linked to several research streams in the literature. Addressing a related topic, Wade (1995, 1996) has found that as the number of competing designs increased in the microprocessor market, the entry of alternative designs first increased and then decreased; similarly, the entry of second source (e.g., organizations that had a stake in the design) into a technological community first increased and then decreased. Drawing from Hannan and Freeman's (1988) density dependence theory, Wade (1995, 1996) explains that when the density of competing designs is low, legitimation effect tends to dominate, encouraging more design sponsors and second source providers to enter the market. As the density continues to grow, however, competition effect will eventually dominate, which makes the product class less attractive and thus reduces entry rate of design sponsors and second source providers.

Our research differs from Wade's (1995, 1996) studies. Broadly speaking, Wade (1995, 1996) has primarily focused on how competing designs may affect the competitive condition; in contrast, we examine how design-based competition will influence organizational outcome for design-based entrepreneurs. While we also consider the competing effects of legitimation and competition, our research suggests that the effects of these mechanisms may differ from the traditional density-dependence theory, at least, when the exit (or survival) of design-based entrepreneurs is the focal point of research. Specifically, our research suggests that the first few competing designs impose a very strong influence on the performance of a specific design-based entrepreneur, perhaps due to the winner-take-all dynamics. As the number of competing designs continues to increase, however, the additional threat imposed by the presence of more designs might be marginal. On the other hand, the legitimation effect grows steadfastly as additional competing designs enter the market, which eventually outpaces the effect of competition. Nevertheless, we are cautious in interpreting our results because the total numbers of competing designs in the product classes studied in our research were relatively small (the largest number was 12). It is possible that as the number of competing designs continues to increase, the competition effect will again outpace the legitimation effect, as indicated in the density dependence theory.

Our research offers further support for conclusions drawn from prior research on the link between dominant designs and survival of firms. Prior researchers have in general agreed that firms must deploy technology strategies supporting dominant designs; aligning with designs that fail to win dominance may increase organizational hazard (Anderson & Tushman, 1990; Christensen et al., 1998; Suarez & Utterback, 1995; Tegarden et al., 1999). Our research supports this argument by showing that the emergence of competing designs as de facto standards increased design-based entrepreneurs' hazard for exit. Nevertheless, our research raises questions about the relationship between design-based entrepreneurs' technological dominance and sustained competitive advantage. One may argue that the establishment of the firm's design as the dominant technology in the product class should significantly enhance the firm's long-term profitability; however, our study indicates that winning the dominance battle at one point of time may not necessarily decrease design-based entrepreneurs' likelihood to exit. While we have presented several potential reasons to explain this phenomenon, future research should use fine-grained measures to fully address this process, in particular, why successful dominant technology leaders such as Lotus Development and Netscape Communications would soon lose their leadership.

Our research highlights the role of design-based entrepreneurs' competitive repertoires. Research on competitive dynamics has posited a positive link between firms' complexity in the competitive repertoire and performance (Ferrier et al., 1999; Miller & Chen, 1996; Yu et al., 2009). Consistent with prior research, our research confirms that design-based entrepreneurs competing with higher degree of concentration in the competitive repertoires (lower degree of competitive complexity) in general have had higher hazard for exit. However, our research suggests that the effectiveness of such a strategy may depend on the status quo of the entrepreneurial firm. Miller and Chen (1996) have provided evidence that market stability moderates the relationship between firms' concentration in competitive actions and performance. Consistent with their study, our results have shown that once the design-based entrepreneur's technology emerges as the de facto standard (a signal of market stability), the negative relationship between a design-based entrepreneur's hazard for exit and its concentration in competitive actions turns positive. Our findings echo Teece's (2007) logic of co-specialization in managing technological ecosystems — a winning design-based entrepreneur is the de facto technology leader who must develop highly specialized skills and routines to manage technological dominance and transit from a specialist to a generalist Utterback and Suárez (1993).

We are aware of the limitations of our research. In conceptualizing technological variation, we have only examined the effects of the total number of competing designs; the characteristics of each design were not formally documented. It is possible that the characteristics of competing designs per se have had caused the exit of design-based entrepreneurs. Nevertheless, our approach represents an important perspective by linking the density of competing designs to the performance of design-based entrepreneurs. Researchers have suggested that design-based competition often occurs between similar technologies (Anderson & Tushman, 1990). We carefully examined the competing designs in our sample to make sure that the competing designs in our study were relatively similar. To follow up with this line of thought, future research should include design-specific measures to capture the subtle differences across designs. We are also aware of the potential bias in our sampling strategy. While we have made painstaking efforts to identify all firms that have been involved in design-based competition, we might still have missed some of the firms, which might eventually bias our results. To reduce such a potential bias, we consulted several industrial and academic experts to make sure that we have captured at least most of the important cases of design-based competition. Furthermore, we used computer-aided coding to capture competitive actions. In spite of the advantages of this method, the reliability of the coding procedure requires researchers' scrutiny in extending the method to other research settings.

Conclusion

Our study makes an important contribution by conceptualizing the mechanism in terms of how technological variation may exert influence on the performance of design-based entrepreneurial ventures. We extend the current density-dependence perspective on technological variation to argue that when the performance of a design-based entrepreneur is the focal point of concern, the effects of legitimation and competition may function in a different pattern. We argue that due to increasing returns mechanism, the competitive threat imposed by a single, or very few, competitors can be severe, which in turn changes the overall joint effects of legitimation and competition, leading to outcomes different from predictions of the traditional density-dependence theory. Our research also extends understanding on the relationship between technological dominance and firms' sustained competitive advantage. Our results suggest that while the dominance of a competing design in the market may increase the likelihood of the focal design-based entrepreneur to exit, the technological dominance of its own design, however, does not necessarily enhance its survival. Furthermore, our research contributes to the competitive dynamics research by re-examining the relationship between competitive repertoire and firm performance in design-based competitive engagement. Consistent with prior research, our results suggest that design-based entrepreneurs concentrating on certain competitive actions in general experience high hazard for exit; however, this relationship demonstrates a different pattern after the new venture's design becomes the de facto standard. Finally and methodologically, we used computer-aided content analysis techniques to operationalize data for competitive actions. Given its efficiency and accuracy, the method appears to have great promise for empirical research in competitive dynamics.

CHAPTER FOUR: TECHNOLOGICAL CHANGE, DOMINANT DESIGNS AND COMPETITIVE DYNAMICS

Introduction

The impact of technological change on industry and organizations has attracted substantial attention among theorists of innovation and strategy. A fruitful research stream has conceptualized technological change as an evolutionary process of technological variation, selection and retention (Anderson & Tushman, 1990). Technological discontinuities introduce variation into otherwise stable technological fields by creating new technological trajectories and markets, followed by a selection process in which social, political and economic forces as well as entrepreneurship initiate competitive dynamics to determine a *standard* or a *dominant design* among various technological variants in the nascent market category (Anderson & Tushman, 1990; Garud et al., 2010; Hargadon & Douglas, 2001; Navis & Glynn, 2010: 441). While some researchers have idealized the outcome of this selection as a winner-take-all solution whereby the entire market will conform to the agreed-upon product configuration defined by the dominant design (Schilling, 1998), more researchers have recognized that the increased popularity of complex technological systems has added considerable complexity to the competitive dynamics surrounding dominant designs (Garud et al., 2002; Garud & Kumaraswamy, 1993; Teece, 2007) — in fact, even after a dominant design has emerged, competitors often follow closely behind to threaten the market leadership, as reflected in the continued battles between Microsoft versus Apple in operating systems, Intel versus AMD in microprocessors, and Google versus Yahoo in search engines.

Process models of dominant designs have suggested varied technological stages in the lifecycle of a discontinuous innovation. Anderson and Tushman (1990) divided the process of technological change into eras of ferment versus retention, suggesting systematic differences between them. Suarez (Suarez, 2004) conceptualized five major phases of a dominance battle — marked by a milestone (e.g., introduction of a product prototype or the emergence of a dominant design), "each phase is characterized by different dynamics that in turn make some of the factors associated with dominance more relevant than others." At the micro-level, firms undertake competitive actions to address various uncertainty and competitive threats caused by industrial dynamism and competitors in each market stage and seek temporary advantages over rivals by "strategic surprise, speed, and simultaneous and sequential thrusts" (Bettis & Hitt, 1995; Rindova et al., 2010: 1475). However, the problem with the conceptions of the process models of dominant designs is that they do not clearly reveal the co-evolvement of competitive dynamics with technological innovation, which calls for more research on how competition unfolds along the life cycle of dominant designs.

We believe the sustained work on competitive dynamics provides a useful lens to observe the competitive process associated with dominant designs. Rooted in the Austrian view of the market as a disequilibrium system, the competitive dynamics research argues that competitive advantage is temporary and dynamic, embedded in the streams of competitive actions that firms undertake to disrupt the market positions of competitors (Jacobson, 1992; Rindova et al., 2010; Schumpeter, 1934b, 1950). Because of the rapid changes in technological field, firms competing to define dominant designs must remain unconfined from traditional practices and to be receptive to new actions in the response to industrial dynamism and competitors' actions to succeed in new competitive landscapes in distinct technological stages (Bettis & Hitt, 1995; Chen et al., 2010). As a result, the competitive dynamics will demonstrate different patterns as technology evolves along the life cycle.

To observe the overall characteristics of firms' competitive behavior, competitive dynamics research has underscored three attributes of competitive actions to define the aggressiveness of rivaling firms: *frequency* (i.e., number of actions undertaken), *magnitude* (i.e., resources committed to each action), and *complexity* (i.e., the different types of actions taken) (Ferrier, 2001; Rindova et al., 2004; Yu et al., 2009). In this paper, we discuss how the frequency and complexity of firms' competitive actions to ferment dominant designs co-evolve along the life cycle of technological discontinuities. We examine the influence of three factors: the *maturity* of the technological market, the *density* in the market category, and the *emergence of dominant designs* in the market category.

We tested our hypotheses using a sample of 145 market categories (with total 358 technological designs) sponsored by 253 organizations. We found that technological leaders sponsoring alternative designs compete more fiercely in the post-dominant design phase, in terms of both frequency and complexity of competitive action. Our longitudinal observation suggests that the maturity of a technology-based market category — captured by the age of the market category — has strong implication on the pattern of competitive dynamics in a market category. Specifically, our research suggests that the frequency of action between technologies pursuing dominant designs follows an S-curve (first increase and then decrease) along the linage of a nascent market category; however, competitive complexity linearly increases over time as the market turns mature. We also found a strong association between patterns of competitive dynamics and density — i.e., the total number of competing technological leaders. We found density in general increases the frequency of action, but this association becomes weaker after the emergence of a dominant design. In contrast, we found a curvilinear (inverted-U shaped) relationship between density and action complexity.

Theory Development

Technological change and dominant designs

The evolution of technology is characteristically embedded in long periods of accumulation of research and development investments, knowledge acquisition, design of commercialized prototypes, and trial-by-error processes to introduce newly developed products to the market (Suarez, 2004; Tushman & Anderson, 1986). Often unpredictably, a major technological advance may become a discontinuous force to disrupt the ordered process of technological change through sharp increases in price-performance ratio (Tushman & Anderson, 1986), new substitutes to change older ways of doing things (Hargadon & Douglas, 2001), or unprecedented functions to create new market categories (Navis & Glynn, 2010). As a technological discontinuity generates new demands by either opening a new market category or a powerful substitution of a previous one, the competition in the emerging technological order is substantial as alternative technological designs compete for dominance (Wade, 1995). This competitive process is characterized by a socio-cultural process of technological variation, selection and retention, marked by the emergence of a dominant design in the market category (Anderson & Tushman, 1990; Srinivasan et al., 2006; Suarez, 2004).

Rendered by new technologies that introduce changes into otherwise stable technological spaces, technological variation is chaotic, characterized by a trial-by-error process in which firms struggle to absorb the innovative technology through alternative approaches (Anderson & Tushman, 1990). When blue laser was first used in the DVD industry, for example, Sony and Toshiba pursued respective technical approaches, Blu-ray DVD (Sony) and HD DVD (Toshiba), to utilize the technical improvements initiated by the new technology. New market categories originating from such new technologies are “unstable, incomplete and disjoined conceptual systems held by market actors” (Rosa et al., 1999: 64), requiring firms sponsoring new technologies to work collectively to make the new category both understandable and appealing to various actors including consumers, analysts, investors, and complementary producers (Navis & Glynn, 2010). In this technological ferment, sponsoring firms of a new technology are in the trial process to find the best combination of various parameters that reconcile the conflicts between cost, performance and technical feasibility, and products based on the new technological order not only receive strong resistance from the existing technological order whose performance is well understood, but also several versions of the new technology appear because each pioneering firm has an incentive to differentiate its variant from the collective identity (Anderson & Tushman, 1990; Navis & Glynn, 2010). As crude initial designs rapidly improve over time, firms sponsoring alternative technical approaches face ever-changing competitive dynamics in distinct market stages (Tushman & Murmann, 1998).

Technological variation is accompanied by a selection process to determine a dominant design whereby several technical alternatives compete until a preferred technological trajectory becomes evidently the market leader (Suarez, 2004). New market categories where dominant designs tend to emerge evolve in a rapid, complex, and unpredictable manner characterized by frequent emergence of technological discontinuities and standards, as reflected in the rapid changes in computers, software, mobile phones, databases and Internet-based products and service. The success of a technological product in the dominance battle is becoming increasingly interdependent with other technologies and firms that decide the basic pace of change in a market category are those that define the rules by which new technologies can deliver value to customers, entices buyers by added value, converts customer purchases to profit, and constantly introduce new functional features to generate more demands (Teece, 2007). For periphery firms, the competitive dynamics among the core players offer a flitting window of opportunity to make key technological decisions (e.g., adoption of which technology and timing of entry) prior to the emergence of a dominant design, whereby incorporating a positively chosen technology is critical (Christensen et al., 1998). While the process of technological ferment are similar when going from simple product to complex systems, the product with higher levels of technological complexity will normally change faster as more actors are involved to initiate changes at various levels in the design architecture.

The competitive dynamics in technological ferment to define dominant designs today is also characterized by the presence of “network externalities” (Farrell & Saloner, 1986; Garud et al., 2002; Katz & Shapiro, 1985). Network externalities exist when the utility of using a product increases as more others use compatible products (Sheremata, 2004). In market categories represented by technological systems (network markets), the degree to which technological systems are compatible with and supported by various complementary products determines network boundaries of the core technology and these boundaries are becoming increasing obscure due to technological convergence — previously disparate technologies tend to integrate to render initially distinct technological / industrial boundaries blurred (Lee, 2007), which in turn increases the scale of competition in the later stage of technological field.

Managers steering the direction of technological ferment are also required to develop a mindset that allows cooperation with competitors. Strategic actions to achieve and maintain technological dominance are often beyond the scope of a single firm and even competitors sponsoring alternative technological trajectories may need to work together to develop more and better new technology in order to remain competitive. Strategic alliances are particularly prominent in cases where core technological knowledge and know-how are collectively possessed by core players in the industry (Afuah, 2000; Lechner, Dowling, & Welpe, 2006; Suarez, 2004). Yet the timing of such collaboration is critical. For example, the personal computer industry is characterized by the competition between two basic designs with the current dominant design being IBM and Microsoft personal computing architecture and the other being Macintosh computer from Apple Computer Company. In spite of the competition, there has been increasing collaboration between IBM and Apple to jointly develop new technologies. However, technology partnering between IBM and Apple only occurred several years later after IBM and Microsoft had obtained dominance (Baum & Korn, 1999; Hagedoorn et al., 2001) .

Technological variants positively selected as dominant designs evolve through relatively minor technique improvements and increased interdependences with other technologies and a community of practitioners (Anderson & Tushman, 1990; Wade, 1996), shifting the locus of innovation in the industry from technological ferment, characterized by trials and errors, to elaborating the agreed-upon “rules of engagement” guided by the chosen technological standards (Garud et al., 2002; Sahal, 1981). This shift is particularly required for dominant designs involving the innovation of complex technological systems that consist of a core technological base, or a platform, and numerous related pieces of technology developed separately by different manufacturers (Cusumano & Gawer, 2002; Funk, 2003; Murmann & Frenken, 2006). Since each technological system is supported by a co-specializing network of complementary actors collectively possessing the skills and resources required in the development of innovation, collective action is often required for a selected technological variants to remain dominant (Hargrave & Van De Ven, 2006; Wade, 1996).

Empirical studies has documented the emergence of dominant designs in various market categories, including personal computers (Tegarden et al., 1999), Internet browsers (Windrum, 2004), microprocessors (Wade, 1995), word processing software (Srinivasan et al., 2006), and local area networks (Soh, 2010). However, the competition for dominance can persist in long periods of time in some market categories without any clearly defined dominant designs, such as what has happened in the markets for camcorders, supercomputers, video game consoles (Srinivasan et al., 2006). In some other market categories (e.g., operating systems, microprocessors, search engines), the emergence of a dominant design fails to crowd out alternative designs and competition among several technological trajectories competitors may persist as competitors constantly threaten the market leadership.

Dominant designs and competitive dynamics

The competitive nature of the dominance battle calls a systematic understanding of how competitive dynamics unfolds in the process of technological change and the emergence of dominant designs. Research on competitive dynamics typically focuses on firms' competitive actions, defined as individual moves that firms undertake to enhance market positions (Chen, 1996; Chen & MacMillan, 1992; Chen et al., 1992; Smith et al., 1991), and conceptualizes inter-firm rivalry as an interactive process of competitive attacks by challengers and competitive responses by defenders (Chen & MacMillan, 1992; Chen et al., 1992; Gatignon & Reibstein, 1997; Smith et al., 1991). Rindova et al. (2004) considered the competition for dominant design as a process characterized by excessive competition with warlike characteristics. Similarly, other researchers have referred to the dominance battle as the "standards war" between firms sponsoring rivaling technologies that compete to define de facto leadership in a market category (Anderson & Tushman, 1990; Shapiro & Varian, 1999a; Soh, 2009; Stango, 2004). Strategists have well understood that selecting a de facto technological leader involves fierce competition; the dynamics of this contest is reflected in the literature by use of varied units of analysis, with conflicting conclusions (Anderson & Tushman, 1990; Farrell & Saloner, 1986; Robertson & Gatignon, 1986; Shankar & Bayus, 2003; Sheremata, 2004; Srinivasan et al., 2006; Stremersch & Tellis, 2002; Tassey, 2000).

While there are several studies that conceptualize competing firms as competitive pairs whose payoffs are highly interdependent (Auriol & Benaim, 2000; Besen & Farrell, 1994; Gallagher & Park, 2002; Rindova et al., 2004; Shankar & Bayus, 2003; Shapiro & Varian, 1999a), the understanding of the dynamic processes in which firms conduct head-to-head competition to win the standards war is still incomplete. In particular, there has been no attempt at examining how the competitive dynamics between technological designs co-evolve with the market and technological regime. This inattention to the fundamental layer of competitive paradigm constitutes a significant gap in the literature: after all, it is at this level that actual the standard war occurs and competitive outcome is determined (Chen, 1996; Chen & MacMillan, 1992).

Competitive dynamics research has underscored two attributes of competitive actions to define the aggressiveness of rivaling firms: *frequency* and *complexity* (Ferrier, 2001; Rindova et al., 2004; Yu et al., 2009). Action frequency refers to the total number of actions a firm undertakes to enhance its market position (Ferrier et al., 1999; Yu et al., 2009). The Austrian view of economics suggests that competitive actions are undertaken for profit opportunities (Jacobson, 1992; Young, Smith, & Grimm, 1996); therefore, firms carrying out competitive actions are more aggressive in exploiting more opportunities. Accordingly, we argue that, in general, a greater number of competitive actions reflects a higher level of competitive aggressiveness of the firm (D'Aveni, Dagnino, & Smith, 2010; Ferrier, 2001). Conversely, if resting on their laurels and become complacent, even market leaders may become vulnerable to competitive challenges due to inertia — this is particularly true in market characterized by frequent technological change and variation (Farrell & Saloner, 1985; Miller & Chen, 1994). Empirical studies have also provided evidence that firms undertaking more competitive actions are likely to have better performance (Ferrier, 2001).

Action complexity refers to the extent to which firms utilize different types of actions to compete against rivals (Miller & Chen, 1996; Yu et al., 2009). We define action complexity as firms' propensity to concentrate their competitive actions on a narrow range of different types, as opposed to a broad range of different types (Ferrier, 2001; Yu et al., 2009). Austrian view of economics has suggested that the overall aggressiveness of a firm in the ever-changing competitive market depends at least partially on the ability to surprise competitors by carrying out a *range* of distinct competitive actions (Rindova et al., 2010). The more complex a firm's competitive repertoire, the more difficult competitor can understand the competitive threat imposed by the firm, and it follows that the competitors may feel more difficult to respond. Firms that are able to carry out a complex sequence of actions can attack rivals on multiple fronts to generate competitive advantage. Empirical evidence has shown that in general, competitive complexity is positively related to firm performance (Ferrier, 2001; Ferrier et al., 1999; Miller & Chen, 1996).

Hypotheses

Market maturity, dominant design, and competitive dynamics

Suarez (2004) has illustrated several stages in the process for a dominant design to emerge in a market category. In the early phase in which the basic technical characteristics of an emerging technological field are determined, several firms with expertise in the emerging technological order will conduct applied R&D aimed at producing new commercial products. Since the new technological ideas are unproven and there will be various errors in the new technological designs, firms engaging in this process have to make the new category both understandable and appealing to diverse stakeholders — establishing the legitimacy of the new technological field becomes the utmost task for sponsoring firms (Navis & Glynn, 2010). In spite of their relationship as would-be competitors, firms along a specific technological trajectory may collaborate and the battle for dominance has not yet been started at the stage.

The first working prototype of the new technology marks the milestone that a technological trajectory has been proven feasible and has reached the stage for commercialization in the market. A working prototype serves as a powerful signal for competing firms to speed up their product development and seriously consider when they should introduce their own designs to compete with the first mover, marking the start of the dominance battle. In the word processing software market, for example, shortly after the first product WordStar, several similar products, including WordPerfect, MS Word, and NewWord, were introduced by other firms to compete with WordStar. Typically, the first product in the market does not represent the technical front, and since they are sometimes too expensive for the mass market, they often target at the high-end of the market as serve as the "front-runners" of the emerging product class. While front-runners may or may not become the dominant designs in the later stage, the appearance of front-runners ushers the dominance battle into a new stage because the increase in the installed base of the front-runners has the potential to create positive feedbacks to early adoption and "excess inertia" — the work of network economists (e.g., Katz & Shapiro, 1985, 1994) have clearly explained how network externalities can completely change the outcome of technological selection and given the winner-take-dynamics, firms will be extremely alert toward competitive threats imposed by alternative technological designs (Schilling, 1998, 2002; Suarez, 2004). Thus, the intensity of competition reaches the highest level during the time when alternative technologies compete to define the dominant design of the market category.

If a specific technology achieves dominance in a market category, then a dominant design is said to have emerged. Anderson and Tushman (1990: 613) defined a dominant design as "a single architecture that establishes dominance in a product class." If a dominant design emerges, the large installed base becomes a strong defense mechanism to rip off competitive advantages of challenger designs, particularly when there are strong network effects and high switching costs (Sheremata, 2004). In addition, the locus of competition in this post-standard phase shifts from technological ferment to define the dominant design to "within-standard" competition (Gallagher and Park, 2002) between firms that produce "clones" based on the dominant technology. It is therefore often based on production capabilities and process innovation (Utterback and Abernathy, 1975; Utterback and Suarez, 1993) — as the success of Dell Computers illustrates. This phase of within-standard competition is characterized by long periods of incremental change, until a discontinuous technology again starts a new dominance cycle.

Empirical work has cumulated to systematically capture the establishment of a dominant design. Anderson and Tushman (1990) considered a technology as dominant if the technology has more than 50% market share; Christensen et al. (1998) followed more qualitative process by a historical analysis of specific innovations in the hard disk drive industry to indentify four dominant designs; Srinivasan et al. (2006) developed a method that combines both qualitative as well as quantitative information. In spite of this accumulation, Suarez (2004) criticized the extant empirical work on dominant designs because they fail to address the competitive dynamics behind each dominance battle —

for instance, an early front-runner could temporarily become the market leader but other competitors may compete aggressively to close the market share gap and then change the outcome of the dominance battle. In addition, to avoiding being technologically locked out, firms sponsoring alternative technologies will compete even more aggressively after a dominant design has emerged. Empirical work has suggested that absolute dominance characterized by winner-take-all rarely happens in the real world (Lee et al., 2006). For example, even if the IBM PC design had prevailed over the Mac design for years, Apple was still a strong competitor in the personal computer market (Hagedoorn et al., 2001). Thus, we hypotheses that:

> *H1a: The frequency of action between technologies pursuing the dominant design in a nascent market category will be higher after the emergence of a dominant design.*
>
> *H1b: The complexity of competition between technologies pursuing dominant design in a nascent market category will be higher after the emergence of a dominant design.*

While the dominance battle may or may not lead to the emergence of dominant designs, the longitudinal development of technological innovation and related market categories follows the S-curve proposed by Rogers (1983), suggesting that in the later stage of a market category, there will be less customers to make purchase decisions. It follows that firms are less motivated to compete aggressively to attract more customers. In addition, the product life cycle theory suggests that as a technology moves into the mature stage, (1) the sales volume will decline or stabilize and (2) the competition becomes increasingly based on price and profitability diminishes. These factors also reduce firms' motivation to compete aggressively. Thus, in spite of the potential dominant designs, the total competitive actions firms undertake will eventually decline. Thus, we hypothesize:

H2a: The frequency of action between technologies pursuing dominant design in a nascent market category will first increase and then decrease as the market category matures.

While the total number of actions declines as the market category matures in the later stage, the complexity of these actions may not decline. As technologies become mature, they often serve as platforms for various complementary products, provided by other firms, to work together to foster innovation and networks. Evolution of the interfaces between the complementors and the platform involves extremely complex decision rules and interactions. Occasionally, technological leaders may reconcile with complementors to consider alternative ways to make the platform open or proprietary or a hybrid model, and how to provide incentives to stimulate investment by the complementors. The overall decision frameworks become increasingly complex to incorporate issues related to network effects, co-specialization, interoperability, and installed base at various levels (Cusumano & Gawer, 2002; Teece, 2007).

H2b: The complexity of competition between technologies pursuing dominant design in a nascent market category will increase as the market category matures.

Density and competitive dynamics

We define density in a market category as the total number of firms that each introduce a technological trajectory. In the race to define a dominant design, firms controlling alternative designs will compete fiercely to establish technological dominance in the market category (Arthur, 1989; Arthur, 1996; Auriol & Benaim, 2000; Farrell & Klemperer, 2006; Liebowitz & Margolis, 1995; Majumdar & Venkataraman, 1998; Witt, 1997). The competitive dynamics between designs has two major characteristics. First, design-based competition normally involves only a very limited number of designs; however, each design is supported by a large number of periphery complementors (Teece, 2007). Second, due to network effects and learning-by-doing, the dominance of a single design is self-reinforcing (Schilling, 1998, 2002); in effect, the success of one design often results in sharply decreased market shares for other designs (Gallagher, 2007; Katz & Shapiro, 1994; Saloner & Shepard, 1995; Srinivasan et al., 2006; Stremersch et al., 2007). The rise of JVC's VHS, for example, reduced the market share of its major competitor, Sony's Betamax, to minimum (Cusumano et al., 1992). Each single design here represents substantial competitive threat and as the total number of competing designs increases, the overall competitive threat will increase as well. These arguments lead to the following hypothesis:

> *H3a: The frequency of action between technologies pursuing dominant design in a nascent market category will increase as the density of the market category increases.*

The market category may or may not experience the emergence of a dominant design; however, once a dominant design emerges, the competition in the post-dominance phase is often focused on (1) firms that have developed relatively large installed bases to pursue alternative technological designs and (2) the "within-standard" competition between several firms that produce technological clones of the dominant technology. The impact of new comes with other technological trajectories will not be the focus of competition. Thus, we hypothesize:

> *H3b: The influence in the increase of density on frequency of action between technologies pursuing dominant design will be weaker after the emergence of the dominant design in a nascent market category.*

As more firms are involved in the race for dominant designs, firms will seek distinct ways to compete with each other. Researchers in strategy, marketing, and economics have addressed several competitive strategies used by firms attempting to establish technological dominance (e.g., innovation, product strategy, pricing, licensing, merger and acquisition and others) (Eisenmann et al., 2006; Rochet & Tirole, 2003; Suarez, 2004; Warner et al., 2006). Research on hypercompetition has argued that when competition is intense, firms have a strong need to combat rivals through “aggressive competitive actions characterized by strategic surprise, speed, and simultaneous and sequential thrusts” (Rindova et al., 2010: 1475). Ashby's (1956) “law of requisite variety” suggested that the competitive arsenal of firms must have certain degree of complexity to reduce the danger of intense competition (Miller & Chen, 1996).

The increase in the number of firms sponsoring alternative technological trajectories also makes the technological interdependences extremely complex. Few technologies today work only in isolation and at various levels, even head-to-head competitors will develop some coordination and compatibility. This is particularly true if a lot of competitors are involved as co-specialization required to advance more demands in related technological fields enable firms to manage their interdependence with others (Soh, 2010). In that case, collective action becomes the most important competitive strategy for all firms involved, which in turn reduces the availability of alternative competitive approaches. Thus, we hypothesize:

H4a: As the density of a nascent market category increases, the complexity of competition between technologies pursuing dominant design will first increase and then decrease.

H4b: As the density of a nascent market category increases, the competition between technologies pursuing dominant design will increasingly concentrate on collective actions.

Methods

Sample

An appropriate sample to test our hypotheses required identifying market categories whereby dominant designs tend to emerge. Previous empirical studies on dominant designs suffered a major limitation in identifying a substantial number of such market categories. We designed our research to overcome this limitation. By talking to industrial experts and reading extensively various trade journals, we recognized that the emergence of dominant designs is a major industrial event and will likely capture substantial attention in media, so we used this source to locate market categories where dominant designs tended to emerge. Thus, we started with a search process which involved three major steps. In Step One, we developed a thesaurus to capture the core concept of dominant design — a technological design that dominates the market. After we extensively read research publications and trade journals and talked to various industrial experts, we found that the phenomenon could be referred to alternatively in the media using such terms as ‘dominant design’, ‘technology /technological standard’, ‘industry/industrial standard’, ‘standards war’, ‘dominance battle’ and/or ‘standards competition’. For an inclusive search, we included all these keywords to construct our first thesaurus (Thesaurus One).

In Step Two, we launched a search at Lexis-Nexis database using Thesaurus One, yielding more than 10,000 newspaper articles containing at least one keyword. A review of these articles uncovered a number of technological designs involved in creating de facto standards. In further investigation, however, we found that a large portion of these technologies were duplicates and some were irrelevant or ambiguous, which substantially reduced our pool to 167 technologies. We carefully examined each technology to understand which product class it belonged to using following sources: Software Taxonomy and Hardware Taxonomy developed by a leading market research company, technical descriptions offered in public sources such as newspapers, company websites and annual reports, and expert opinions. The investigation indicated that the 167 technological designs belonged to 145 product categories.

Step Three involved an additional search for ‘competitors’ of aforementioned technological designs using a thesaurus (Thesaurus Two) of keywords such as ‘competitors’, ‘competing’, ‘compete’, ‘rival’, ‘defeat’ and many others[19]. This search was necessary because it substantially adjusted the skewness towards more successful technological designs in our search. For example, in the search for technological designs competing to establish de facto standards in spreadsheet market, using Thesaurus One only uncovered two successful technological designs: ‘Lotus 1-2-3’ and ‘Microsoft Excel’; however, using Thesaurus Two, we further identified such technological designs as ‘Quattro Pro’ and ‘VP Planner’, which were unsuccessful rivals against ‘Lotus 1-2-3’. This exhaustive search enabled us to capture most of the technological designs in a given product category.

The final pool included 145 market categories (with total 358 technological designs). A further investigation indicated that these technological designs were

[19] The complete list has 32 keywords and will be provided upon request.

sponsored by 253 organizations in which 188 were firms incorporated after 1980. We then carefully examined the products/technologies of these firms and found that standardization was the core strategy for all firms since their incorporation. Thus, this group of firms constituted an appropriate sample to test our hypotheses.

Identification of competitive actions

A competitive action is defined as an individual move that the firm undertakes to enhance its market position (Chen, 1996; Chen & MacMillan, 1992; Chen et al., 1992; Smith et al., 1991; Yu et al., 2009). To identify the competitive actions of firms participating in the dominance battle, we collected textual data in published news articles and wires from the LexisNexis database. We chose this data source because some researchers argued that investors respond to action announcements as manifested in news release (Westphal and Zajac, 1998). To ensure comprehensiveness, we used multiple data sources from the Lexis/Nexis online database: *PRNewswire, Business Wire, the Associated Press Service, M2Presswire, Newsbyte News Service, Canadian Newswire,* and *Gannett News Service.* We deleted repeatedly reported actions and used the first report to decide the action date. Following Ferrier (1999), we focused on news headlines to identify the competitive actions. When the name or abbreviation of the company led to confusion, we used LexisNexis 's 'intelligent indexing' function to screen out irrelevant headlines, a technique used by Uotila and colleagues (2009). An extensive reading of these news headlines and the literature on competitive dynamics suggested that these competitive actions belonged to 13 categories: 'Introduce a new product / innovation', 'Update an existing product', 'Form product / innovation alliances', 'Form marketing based alliances', 'Merger and Acquisition', 'Open new divisions or restructure the organization', 'Involve in open source development' 'Sign licensing agreement', 'Improve distribution or customer services', 'HR action', 'Price action or Promotion', 'Undertake legal action', 'Participate in trade events'. We validated these categories by consulting several management professors and industrial experts and they agreed that these were the common most types of competitive actions in the information technology industries.

We then used a software package, *PASW Text Analytics for Survey*, to categorize the competitive actions. *PASW Text Analytics for Survey* is a software package developed by SPSS Inc. to code textual data into meaningful categories. There were several advantages of using this software. First, *PASW Text Analytics for Survey* utilized several automated linguistic techniques to enhance the reliability of the computer-aided coding. To assess its accuracy and reliability, we ask two coders to manually coded 600 headlines and then used the software to code the same news headlines; a detailed review of the coding results indicated that there was very high consistency between human and computer-aided coding (greater than 80 percent agreement). The second advantage of using computer-aided coding was that it allowed us to handle large dataset with relatively high efficiency. As the number of observations increased, the impact of a single coding mistake could be substantially reduced (Uotila et al., 2009).Accordingly, we used *PASW Text Analytics for Survey* to code our competitive actions data. The final dataset contained 71,127 competitive actions.

Measures

Frequency of action in a market category. We measured frequency of action in a market category by counting the total number of competitive actions undertaken by firms sponsoring competing designs in a market category. This measure has been used in previous research (Ferrier et al., 1999; Young et al., 1996). We created a yearly measure for this variable.

Action Complexity in the market category. Previous research (Ferrier et al., 1999; Yu et al., 2009) on action complexity has focused on the competitive repertoire at the firm level; in this paper, we extend the analysis to a market category level. Using a similar method, we calculated the complexity of action in a market category by estimating the extent to which firms in the market category carried out a broad range as opposed to a narrow range of competitive actions in year *t*. Using to denote the total number of actions a design-based entrepreneur undertook in a particular type of action *j*, we calculated the overall concentration index in year *t* as follows:

Emergence and Time of de facto Standards. We followed the method of Srinivasan and colleagues (2006) to measure emergence and time of de facto standards. Srinivasan and colleagues' (2006) methodology involved two steps. First, two graduate students content-analyzed various archival sources to identify whether and when a technological design has become a de facto standard (dominant design). Second, the authors validated this measure by collecting market share data[20] and consulting multiple industrial experts. Srinivasan and colleagues (2006) reported high correlation (ρ =.86)

[20] The criteria to decide whether and when a technology has become a de facto standard was that its market share was beyond 50 %, the same criteria used by Anderson and Tushman (1990).

between the de facto standard's emergence times measured respectively by content analysis and market share data.

We utilized the same procedure in this study. We first collected various archival information (e.g. research articles, books, trade journals, newspapers) reporting a particular technological design's involvement in standardization [21]. Two coders (one author and a Ph.D. student) separately read the articles to code whether and when a technological design has emerged as a de facto standard. The two coders unanimously coded the emergence and time of 105 technological designs as de facto standards. We then followed Srinivasan and colleagues (2006) to validate our measure. We collected market share data for each technological design; due to data unavailability, we only found market share data for 60 out of the 145 technologies coded as de facto standards. We then correlated the de facto standards' emergence times identified from two methods. A correlation of .97 was reported, indicating high consistency between two measures. To further enhance our confidence, we invited several industrial experts to review the technological designs we identified as de facto standards and asked them to comment on (1) whether the technological designs should be considered as de facto standards and (2) when the technological designs, if ever, emerged as the de facto standards. Thus, we were reassured of the reliability of our measure.

Market Maturity. We used the age of the market (the difference between the observation year and the year of first product introduction) to capture market maturity.

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[21] We collected relevant research articles by a comprehensive literature review. We found relevant trade journals and newspapers by searching the technology's name together with keywords such as 'standard' , 'dominance', ' winning' and so on.

Total Number of Competing Designs. The three-step search allowed us to develop listings of competing designs in each product category. We then collected information about the entry and exit of each technological design. An entry was recorded when the firm first introduced a design; the information was collected from newspapers in LexisNexis database, and then verified with other sources such as annual report, company website, information provided by other research articles or books. Exit was recorded when the firm discontinued the product line. We also recorded exit of a technology if it completely disappeared from all public sources. In addition, following Tushman and Anderson (1986), exit was also recorded when the firm discontinued operating as an independent firm. With the entry-and-exit information, we constructed yearly listings of competing designs for all product categories to operationalize total Number of Competing Designs (*Number of Competitors*).

Control Variables. We controlled several industry variables to rule out plausible alternative explanations. Consistent with previous research on similarly topics (Nadkarni & Narayanan, 2007),we controlled: (1) market growth, measured as percentage change in industry gross sales in a given year; (2) R&D intensity, measured by R&D expenditures divided by sales; (3) capital intensity, measured by capital expenditures divided by sales; (4) advertising intensity, measured by advertising expenditures divided by sales; and (5) the depreciation rate measured by the average depreciation rate in the industry. All the control variables were computed using data from COMPSTAT.

Analysis

We used fixed effects models to test our hypotheses. Fixed effects models control for unobserved heterogeneity that is constant over time and correlated with independent variables. As we were interested in the change of competitive dynamics over time along the evolutionary path of technological change, this approach had the advantage of capturing the over pattern of time-based variance and therefore was appropriate to test our hypotheses. In testing hypotheses regarding frequency of action, we used the negative binomial model as we used count of actions in a given year as the dependent variable (Chatterji & Toffel, 2010). For models predicting complexity and concentration in collective actions, we used general linear models.

Results

Table 7 includes statistical models testing hypotheses predicting frequency of actions. Model 1 only contained control variables. In this model, R&D intensity was negatively related to frequency of action, suggesting that the increase in firms' R&D investments may reduce the total number of competitive actions in the market place. In contrast, Model 1 found capital intensity and advertising intensity positively related to firms' total competitive actions. Market growth and depreciation rate of the industry was not a significant factor in predicting firms' total actions.

Model 2 and Model 3 tested our hypotheses regarding frequency of action. Model 2 focused on the main effects of our independent variables. In this model, we found the coefficient for emergence of dominant design positive and significant ($\beta = 0.57$, $p<0.001$), suggesting frequency of action was higher after dominant designs emerged in the market categories. In the same model, market maturity was positive and significant ($\beta = 0.04$, $p < 0.5$) and its square term was significant and negative ($\beta = -0.01$, $p < 0.001$) , suggesting an inverted-U shaped relationship between market maturity and frequency of action (See Figure 13). Finally, Model 2 also reported density as a significant antecedent of frequency of action ($\beta = 0.59$, $p < 0.001$), which supported our expectation that density will be positively related to frequency of action. Thus, our hypotheses regarding the main effects on frequency of action (H1a, H2a and H3a) were all supported.

We used Model 3 to test the interaction effect between density and emergence of dominant designs. Figure 14 offers a graphic presentation of the impact of density on firms' frequency of action before and after dominant designs. While there is a positive association between density and frequency of action in both situations, the unit increase of density is associated with more increase in the frequency of action before the emergence of dominant designs than after the emergence of dominant designs. However, the graph indicated that the overall frequency of action is higher after the emergence of dominant designs.

Table 8 includes statistical models testing hypotheses predicting action complexity. Model 5 only contained control variables. In this model, R&D intensity was positively related to frequency of action, suggesting that the increase in firms' R&D investments may increase the complexity of competitive actions in the market place. Model 4 also found capital intensity and positively related to firms' total competitive actions. Market growth and depreciation rate of the industry was not a significant factor (at $p<0.05$ level) in predicting firms' action complexity.

Model 5 ~ Model 7 tested the impact of the emergence of dominant design, market maturity and density on action complexity in a given market category. In Model 5, we found the coefficient for emergence of dominant design positive and significant (β

= 0.76, $p<0.001$), suggesting action complexity was higher after dominant designs emerged in the market categories. In Model 6, market maturity was positive and significant ($\beta = 0.0$, $p < 0.001$), which suggests that as the market becomes mature, the competitive actions in the market category becomes more complex. In Model 7, we included density and its square term and found both density ($\beta = 0.33$, $p < 0.001$) and its square term ($\beta = -0.03$, $p<0.05$) were significantly related to action complexity, which supported our expectation that density will have an inverted-U shaped relationship with action complexity (See Figure 15).

Finally, in Model 8, we tested the impact of density on firms' concentration in collective actions and found a significant, positive relationship between density and firms' concentration in collective actions ($\beta = 0.02$, $P < 0.05$). All our hypotheses regarding action complexity received support in our statistical models.

Discussion

This paper advances the process models of dominant design by focusing on how competitive dynamics in the ferment of dominant designs co-evolve with technology. We found that technological leaders sponsoring alternative designs compete more fiercely in the post-dominant design phase, in terms of both frequency and complexity of competitive action. Our longitudinal observation suggests that the maturity of a technology-based market category — captured by the age of the market category — has strong implication on the pattern of competitive dynamics in a market category. Specifically, our research suggests that the frequency of action between technologies pursuing dominant designs follows an S-curve (first increase and then decrease) along the linage of a nascent market category; however, competitive complexity linearly increases over time as the market turns mature. We also found a strong association between patterns of competitive dynamics and density — i.e., the total number of competing technological leaders. We found density in general increases the frequency of action, but this association becomes weaker after the emergence of a dominant design. In contrast, we found a curvilinear (inverted-U shaped) relationship between density and action complexity.

Our research is linked to several streams of research on dominant designs. First, our findings advance the understanding of the process of dominance battles in technological ferment as discussed by prior researchers such as Anderson and Tushman (1990) and Suarez (2004). While cumulative research on this topic has suggested that there is fierce competition between alternative technologies following a technological discontinuity to ferment a dominant design, this research has remained unclear in terms of the actual process whereby firms exchange competitive actions to formulate a dominant design. However, it is at this level that firms sponsoring alternative technological trajectories encounter each other and compete to gain advantage in the technological diffusion. Our research shed light on the process models of dominant design by directly observing firms' competitive actions. Several findings in our research may highlight our contribution to the dominant design literature. First, in contrast to the punctuated equilibrium model of technological change in which the emergence of a dominant design reduces technological uncertainty, we found that competition among alternative technological designs continues and is even more intense in the post-dominant design phase — this finding is consistent with intuitive observation of many real world cases (e.g., Apple Macintosh versus Microsoft Windows). We found that the force that reduces competition between designs is not the emergence of a dominant design, but the maturity of the market — as the market turns mature, the competition to define a dominant design becomes less intense.

Second, we research extends the conversion regarding the relationship between population density and technological dominance initiated by Wade (1995, 1996). However, our work differs from the hypotheses developed by Wade as we focus on how density influences competitive dynamics in nascent market categories. We found that in general the increase in density increases firms' propensity for competitive actions in a market category — as captured by total number of competitive actions undertaken by firms, whereas the types of actions firms choose to contend rivals first increase and then decrease as more competitors are involved. We found this curvilinear relationship perhaps has to do with firms' increasing focus on collective actions — as more competitors are involved in technological ferment, there is an increasing need for firms to work with other firms and the dominance battle is centered on the competition formulate collective action in the technological field, thereby narrowing firms' competitive weapons.

Our research has several limitations. First, competitive dynamics has various facets and our research only addresses factors that we considered most relevant to our topic. However, the sustained work on competitive dynamics has introduced diverse perspectives and future research may incorporate these perspectives to advance our understanding of the dominance battle. Second, our research only focuses on the competitive dynamics between firms introducing alternative designs in nascent market categories and the competition between firms producing "technological clones" is not addressed in our research. Prior researchers have suggested that in the period after a dominant design has emerged, the locus of competition may shift from the rivalry between alternative designs to "in-group" competition (Anderson & Tushman, 1990). Future research may systematically examine how the "in-group" competition may co-evolve with technology. Empirically, we research only examines cases in relatively fast-changing industries and does not reflect the competitive dynamics in slow-changing industries. Future research should extend this research to capture the evolution of competitive dynamics in slow-changing industries.

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Table 1
A Summary of Primary Research Streams and Key Arguments

Perspective	Theme	Code	Mechanism	Key Arguments
Natural-selection	Process models of technology change	NS-01	Technological paradigms	Technological change resembles the process of paradigm shift: major scientific breakthrough can introduce a new paradigm to replace the existing one, however, the rise of the new paradigm stems from the interplay among scientific advances, social institutions and economic forces.
			Punctuated equilibrium model	Technological change is characterized by long periods of incremental change punctuated by technological discontinuities.
			Technological complexity	The process of standard-based competition is more complex when each technological design represents a technological community consisting of technological leaders, periphery firms, institutional actors and users of various preferences.
	Factors that lead to the emergence of standards	NS-02	Network externalities and increasing returns mechanism	Because of network externalities, there are increasing returns to the installed base of a technology standard which may overturn competitive outcome.
			Switching costs and path dependence	The adoption of a new technology may imply investment in terms of hardware, software, skills, and network resources, creating switching costs to make the markets for technology standards “tipping”.
			Government policy and intellectual property regimes	Government policy on the one hand permits collaboration required for technology innovation, while on the other hand prosecutes violation of antitrust law to intervene into the process for de facto standards to emerge. If strong intellectual property rights hinder innovation, the government should bring in antitrust action.
	Industry structures	NS-03	Winner-take-all dynamics	A winning standard will govern a large user base and the more it gains prevalence, the more likely it will emerge as the sole technological design in a given market category and kick out alternative designs.
			Two-sided market	A technological platform becoming the standard often serves as the inter-mediating platform to connect two distinct user groups that are called (1) “sellers” who produce complementary products for the platform and (2) “buyers” who desire the synergy of the standard and complementary products.
			Technological ecosystems	A complex technological system involves one or a few core firms that decide the standards for product design and number periphery firms produce complementary product to support the standards.

System-structure	Time-related adaptation	SS-01	Strategic fit with technological stages	Firms are born to win or lose the natural selection associated with technological change; rather, incumbent firms may react by adjusting administrative and production structures in accord to dynamics of industrial innovation.
	Technology-based adaptation	SS-02	Incorporation of technology standards	Firm incorporating designs that become standards have better survival chance. For firms that initially use other designs, if they shift to what has become the "dominant design", they will still have better survival chance.
			Compatibility	If a standard is embedded in a complex technological system, adaptive firms' profitability may depend on its compatibility with the platform and other complementary products.
			Open source	Adaptive firms may use different business models to pursue open source standards. Their adaptive strategies may depend on organizational size and age.
	Market-based adaptation	SS-03	Network effects	If a firm adopts a new innovation early, the influence of network effects is contingent on factors such as radicalness of new technology, technological intensity of products and incumbency of the firm.
			Switching costs	Switching costs influence profits of firms introducing radical innovation to the market.
Strategic-choice	Institutional entrepreneurship	SC-01	Institutional entrepreneurship	Standard-setting firms are institutional entrepreneurs who introduce change to otherwise stable institutional spaces. By seeking legitimacy, institutional entrepreneurs can accomplish technological leadership in the industry.
	Technology and product strategies	SC-02	Proprietary versus open platforms	The degree of openness of a standard, varying from purely proprietary to completely open, may influence the establishment of technological dominance and profitability in different ways.
			Compatibility and bundling strategies	Compatibility is functionally critical when innovative firms desire to shift the locus of standards from an existing new technological system to a new one. In setting standards, firms may leverage the installed base of an established product by bundling a new, compatible product to it.
			Learning and innovation	For firms controlling complex technological systems, integrating know-how from outside and within the firm is critical — the creation of learning, knowledge sharing and knowledge integration are important.
	Role of resources	SC-03	Complementary products	Availability of complementary products may influence the success of the core technology.
			Installed base	Firms' installed base is a critical resource to provide competitive advantage.

Collective-action	Drivers of collective action	CA-01	Complexity of technological systems	Facilitating standards in complex technological systems requires the collective efforts of various agents including in- and out-house innovation units, manufactures of core and periphery components, the government, industrial associations, and various technological users.
			Government action	Government may exert influence on forecasted and actual installed base of a technological system, the amount of competition in the market, and the degree of openness in technology, which controls cooperation and competition in the standards battle.
			Motives of the firm	Institutional entrepreneurs are motivated to formulate collective action with firms who collectively possess the technology and know-how to advance innovation in the industry.
	Forms of cooperation and competition	CA-02	Hierarchy of a technological community	On top of a technological community is the core firm controlling the platform and standards, and fierce competition may occur between core firms controlling different technological communities.
			Proprietary versus open source platforms	The form of cooperation with a proprietary standard depends on IPRs. Open source represents an "extreme" form of cooperation which ties the role of network externalities to speed of diffusion of standards.
	Mechanisms to create standards	CA-03	"Strategic maneuvering"	Coalition of the core firm with numerous complementary firms and industrial organizations may lead to the creation of standards.
			Committees	Industrial committees represent the de jure mechanisms to create technology standards through collective action.
			Social mechanisms	Standards emerge out of a social-political process of comprise and accommodation in a specific institutional space.

Table 2
Research Methods Used in Empirical Studies

	Natural Selection View	System Structure View	Strategic Choice View	Collective Action View
Case Study	10	1	9	6
Interview	1	1	3	4
Survey	4	2	1	2
Simulation	3	1	0	2
Archival Data (case study not included)	15	8	6	4

Table 3

Research Opportunities in Theoretical Integration

Method of Integration	Future Directions
Incorporation of Boundary Conditions	• *Technological complexity.* Introduce more complex process models to incorporate the impact of increasing technological complexity on the standardization processes • *Institutional environment.* Advance theories of standards in global settings.
Integration among the four perspectives	• *Strategic choice and system structural views*. This integrative perspective will examine how complementors will react to the "ecosystem" controlled by technological leaders. • *Collective action and natural selection views*. This perspective can be used to examine the patterns of cooperation among firms from a longitudinal perspective. • *System-structural and collective-action views.* This approach is useful in investigating the interactions between firms' reaction to the system and the collective action of the technological regime.
Persistent debates	• *Ontological differences may persist.* For example, it is convenient to attribute a priori voluntaristic behavior to standard setting firms and deterministic behavior to those firms that are adapting to standards. However, from a voluntaristic perspective both may see as the willful decision of the firms: some firms proactively decide they will adapt to standards instead of creating them

Table 4

Research Opportunities in Each Perspective

Perspective	Future Directions
Natural Selection	• Conduct research to address the competitive dynamics in the post-standard era.
System-structural	• Research on entrepreneurial firms that engage in standards-based competition.
Strategic-choice View	• Utilize the action-response perspective to investigate how firms' strategies will shape industrial standards. • Investigate firms’ performance after they establish technology standards.
Collective Action View	• Theorize the collective action in standardization using the social movements perspective. • Incorporate the economics of collective action.

Table 5

Industry Conditions and Design-based Entrepreneur's Hazard for Exit - Results from Event History Analyses

	Cox Models						Log_Log Models					
Variables	Model C1	Model C2	Model C3	Model C4	Model C5	Model C6	Model LL1	Model LL2	Model LL3	Model LL4	Model LL5	Model LL6
Intercept							-7.62***	-8.26***	-7.90***	-8.37***	-8.31***	-8.31***
							(1.52)	(1.51)	(1.48)	(1.52)	(1.50)	(1.50)
Control Variables												
Market_Size[a]	-0.34*	-0.25+	-0.34*	-0.25+	-0.31*	-0.32*	-0.19	-0.15	-0.21	-0.13	-0.17	-0.17
	(0.14)	(0.15)	(0.15)	(0.15)	(0.15)	(0.15)	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)	(0.16)
Market_Competition[a]	0.49*	0.36+	0.52*	0.36+	0.43+	0.44*	0.51*	0.46*	0.57**	0.43*	0.48*	0.48*
	(0.21)	(0.21)	(0.21)	(0.21)	(0.22)	(0.22)	(0.20)	(0.21)	(0.21)	(0.20)	(0.21)	(0.21)
Firm_Size[a]	-0.07**	-0.06**	-0.07**	-0.06**	-0.05*	-0.05*	-0.22***	-0.21***	-0.21***	-0.21***	-0.21***	-0.21***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Firm_Age	-0.06+	-0.08*	-0.06*	-0.08*	-0.08*	-0.08*	0.07**	0.05**	0.05**	0.05*	0.05*	0.05*
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Firm_IPO	0.86**	0.74**	0.83**	0.74*	0.62*	0.62*	1.67***	1.57***	1.63***	1.56***	1.54***	1.54***
	(0.30)	(0.30)	(0.30)	(0.30)	(0.31)	(0.31)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)	(0.28)
Firm_VC_Funding	0.04	0.03	0.02	0.04	0.05	0.04	0.10	0.18	0.11	0.21	0.23	0.23
	(0.23)	(0.23)	(0.23)	(0.23)	(0.24)	(0.24)	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)
Firm_Total_Action	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01+	-0.01	-0.01	-0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Year 80-89	-0.59+	-0.23	-0.54	-0.23	-0.26+	-0.26	-0.62**	-0.55	-0.62**	-0.51*	-0.47*	-0.47*
	(0.36)	(0.37)	(0.36)	(0.37)	(0.37)	(0.37)	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)
Independent Variables												
Number of Competitors		0.51***		0.51***	0.49***	0.53***		0.51***		0.50***	0.57***	0.57***
		(0.15)		(0.15)	(0.15)	(0.16)		(0.15)		(0.15)	(0.16)	(0.16)
Num of Competitors Square		-0.05*		-0.05*	-0.04+	-0.04+		-0.06**		-0.06*	-0.06**	-0.06**
		(0.02)		(0.02)	(0.02)	(0.02)		(0.02)		(0.02)	(0.02)	(0.02)
Competitor Standard			0.54***						0.71***			0.60**
			(0.16)						(0.18)			(0.22)
Own Standard				0.02	0.60	0.89+				0.31	0.82*	0.86*
				(0.20)	(0.37)	(0.48)				(0.20)	(0.36)	(0.48)
Own Standard × Num of Competitors					-0.19+	-0.46					-0.20	-0.25
					(0.11)	(0.33)					(0.13)	(0.37)
Own Standard × Num of Competitor Square						0.04						
						(0.05)						
Number of Observations	186[b]	186	186	186	186	186	2354[b]	2354	2354	2354	2354	2354
AIC	891.27	871.91	883.50	873.91	846.27	847. 51	737.89	726.61	726.09	726.46	725.51	727.49
Wald	39.74	60.64	49.95	60.56	57.40	57.70						
Likelihood Ratio	41.92	65.28	51.69	65,29	63.70	64.46						
Log-Likelihood							-359.94	-352.30	-353.05	-351.23	-349.76	-349.75

[a] Logarithm
[b] Observations used in Cox models were based on firms. Observations used in Log-log models were based on firm-year.
Standard errors in parentheses
+ p <0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table 6

Firm Strategy and Design-based Entrepreneur's Hazard for Exit - Results from Event History

Parameter	Cox Models Model C7	 Model C8	 Model C9	 Model LL7	Log Log Models Model LL8	 Model LL9
Intercept				-7.96***	-8.27***	-8.62***
				(1.68)	(1.67)	(1.74)
Controls						
Market Size[a]	-0.33*	-0.32*	-0.33*	-0.17	-0.14	-0.12
	(0.15)	(0.15)	(0.15)	(0.17)	(0.17)	(0.17)
Market Competition[a]	0.45*	0.45*	0.48*	0.52*	0.47*	0.47*
	(0.21)	(0.21)	(0.21)	(0.20)	(0.20)	(0.20)
Firm Size[a]	-0.06**	-0.06*	-0.06*	-0.21***	-0.21***	-0.21***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)
Firm Age	-0.11***	-0.11**	-0.11***	0.06**	0.05*	0.05*
	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)
Firm IPO	0.81**	0.61*	0.60+	1.62***	1.51***	1.51***
	(0.30)	(0.31)	(0.31)	(0.28)	(0.28)	(0.28)
Firm VC Funding	-0.04	-0.02	-0.06	0.06	0.08	0.05
	(0.23)	(0.24)	(0.24)	(0.22)	(0.23)	(0.23)
Firm Total Action	-0.01+	-0.01*	-0.01+	-0.01	-0.01	-0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Year 80-89	-0.09	-0.07	-0.04	0.55*	-0.44	-0.36
	(0.37)	(0.37)	(0.37)	(0.23)	(0.23)	(0.24)
Num of competitor	0.22***	0.20***	0.20***	0.11*	0.11*	0.10*
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Independent Variables						
Own Standard		-0.06	0.53		0.28	0.87**
		(0.20)	(0.33)		(0.20)	(0.31)
Concentration		1.08***	1.42***		0.63*	0.98**
		(0.30)	(0.33)		(0.29)	(0.32)
Concentration × Own Standard			-1.50*			-1.58*
			(0.72)			(0.71)
Number of Observations	186[b]	186	186	2339[b]	2339	2339
AIC	914.65	883.44	883.44	746.91	744.24	740.96
Wald	57.13	69.53	73.17			
Likelihood Ratio	59.66	69.02	73.62			
Log-Likelihood				-360.45	-360.12	-357.48

[a] Logarithm;
[b] Observations used in Cox models were based on firms. Observations used in Log-log models were based on firm-year.
Standard errors in parentheses
+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7
Results of Negative Binomial Regression with Frequency of Action as DV

Variables	Model 1		Model 2		Model 3	
Intercept	3.75	**	2.87	**	2.90	**
	(0.08)		(0.11)		(0.11)	
R&D Intensity	-0.11		-0.07		-0.08	
	(0.04)		(0.03)		(0.03)	
Capital Intensity	0.16	*	0.074		0.08	
	(0.04)		(0.03)		(0.03)	
Advertise Intensity	0.17		0.10		0.10	
	(0.07)		(0.05)		(0.05)	
Market Growth	0.00		0.00		0.00	
	(0.00)		(0.00)		(0.00)	
Depreciation	0.01		0.00		0.00	
	(0.01)		(0.00)		(0.00)	
Emergence of Dominant Design			0.57	**	0.55	**
			(0.07)		(0.07)	
Market Maturity			0.04		0.04	
			(0.02)		(0.02)	
Market Maturity Square			-0.01	**	-0.01	**
			(0.00)		(0.00)	
Density			0.59	**	0.69	**
			(0.02)		(0.04)	
Density × Dominant Design					-0.14	*
					(0.05)	
Years Dummy	Yes		Yes		Yes	
Dispersion	1.87		0.99		0.98	
	(0.07)		(0.04)		(0.04)	
DF	1067		1063		1062	
Pearson Chi-Square	2366.962		1595.383		1609.852	
Scaled Pearson X2	2366.962		1595.383		1609.852	
Log Likelihood	165417.8		165846.3		165851	
Full Log Likelihood	-4859.71		-4431.2		-4426.48	
AIC (smaller is better)	9737.425		8888.406		8880.965	
AICC (smaller is better)	9737.594		8888.749		8881.361	
BIC (smaller is better)	9782.246		8953.147		8950.686	

*** p<0.001, **p<0.01, * p< 0.05 (two-tailed), ++ p<0.05 (one-tailed)

Table 8
Regression Results with Action Complexity as the Dependent Variable

Parameter	Model 4		Model 5		Model 6		Model 7		Model 8[Δ]	
R&D Intensity	0.04		0.03		0.06		0.04		0.00	
	(0.06)		(0.05)		(0.06)		(0.05)		(0.01)	
Capital Intensity	0.12	***	0.13	***	0.15	***	0.11	**	0.01	*
	(0.03)		(0.03)		(0.04)		(0.03)		(0.01)	
Advertise Intensity	-0.01		-0.05		-0.10		0.01		0.02	
	(0.07)		(0.07)		(0.07)		(0.07)		(0.02)	
Market Growth	0.00	+	0.00		0.00	+	0.00		0.00	
	(0.00)		(0.00)		(0.00)		(0.00)		(0.00)	
Depreciation	-0.03	+	-0.04	*	-0.02	+	-0.03	*	0.00	
	(0.01)		(0.01)		(0.01)		(0.01)		(0.00)	
Emergence of Dominant Design			0.76	***						
			(0.13)							
Market Maturity					0.08	***				
					(0.02)					
Density							0.33	***	0.02	*
							(0.05)		(0.01)	
Density Squared							-0.03	*		
							(0.01)			
Years Dummy	Yes		Yes		Yes		Yes		Yes	
R Square	0.42		0.44		0.43		0.46		0.29	
F	4.38		4.78		4.58		5.08		2.49	

n=919

*** p<0.001, **p<0.01, * p< 0.05 (two-tailed), ++ p<0.05 (one-tailed)

[Δ]Model 8 used Concentration in Collective Action as the dependent variable

Figure 1. Number of Papers by Journal

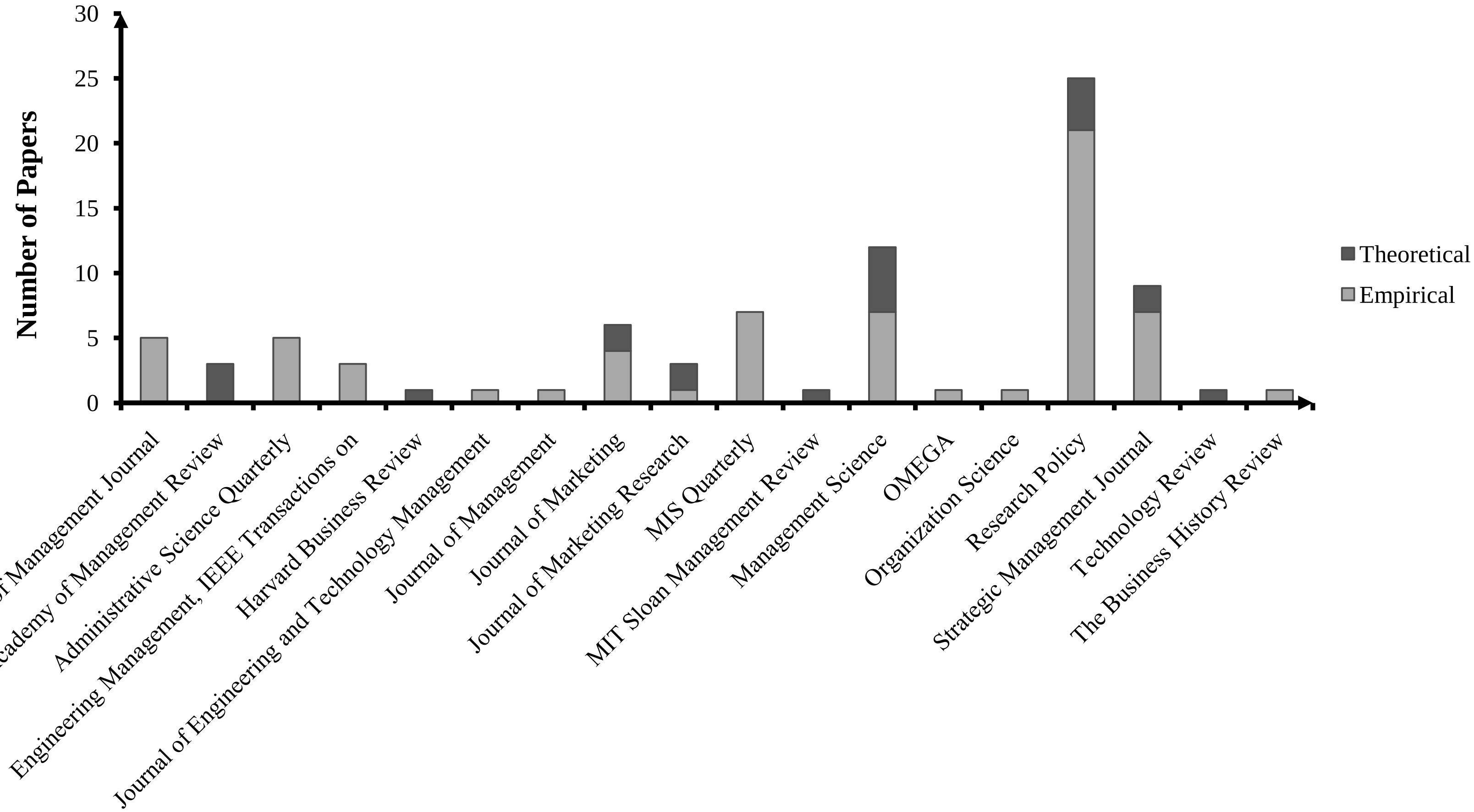


Figure 2. Number of Papers by Year

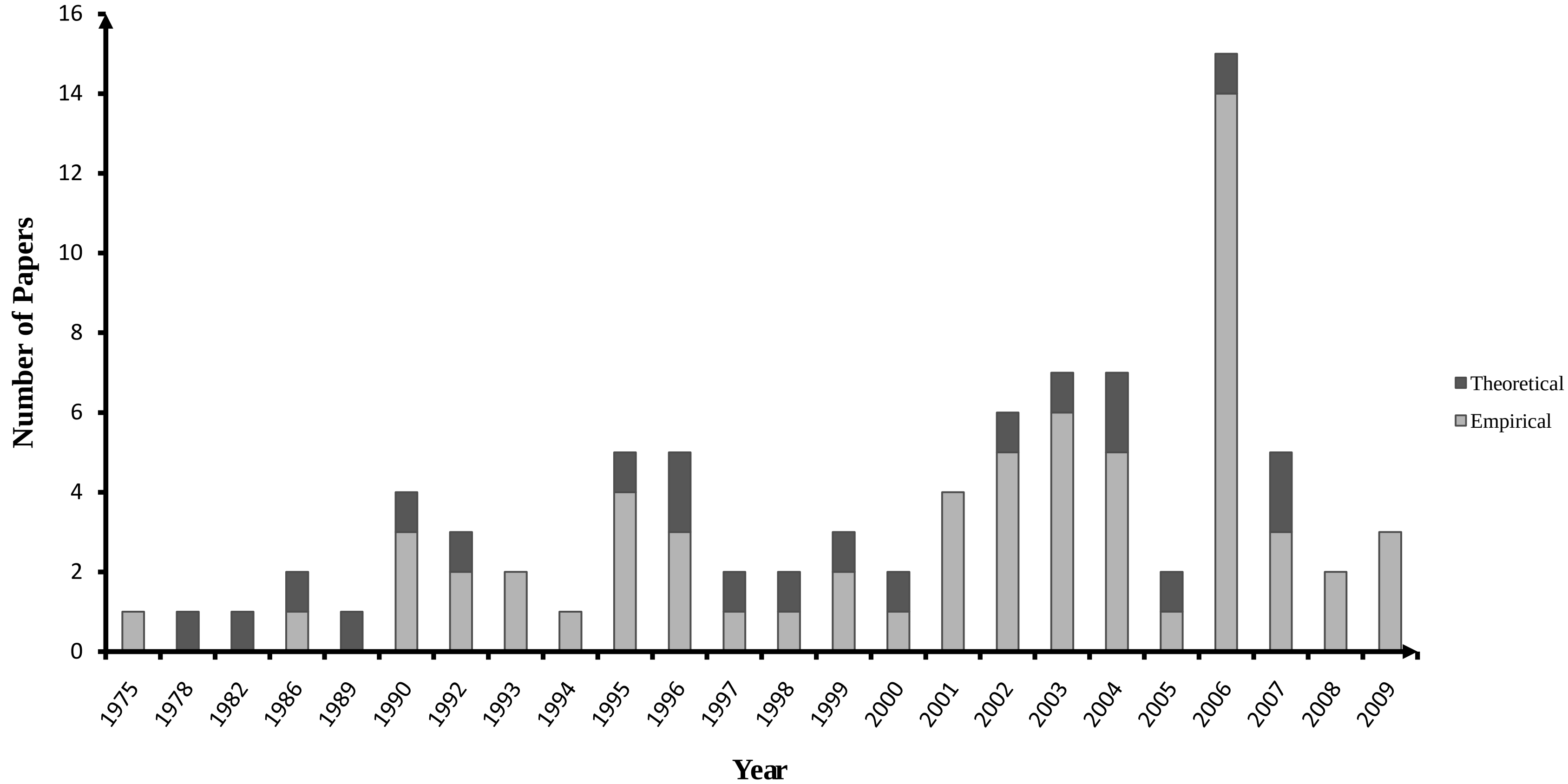


Figure 3. A Graphic Presentation of the Scholarly Community on Technology Standards

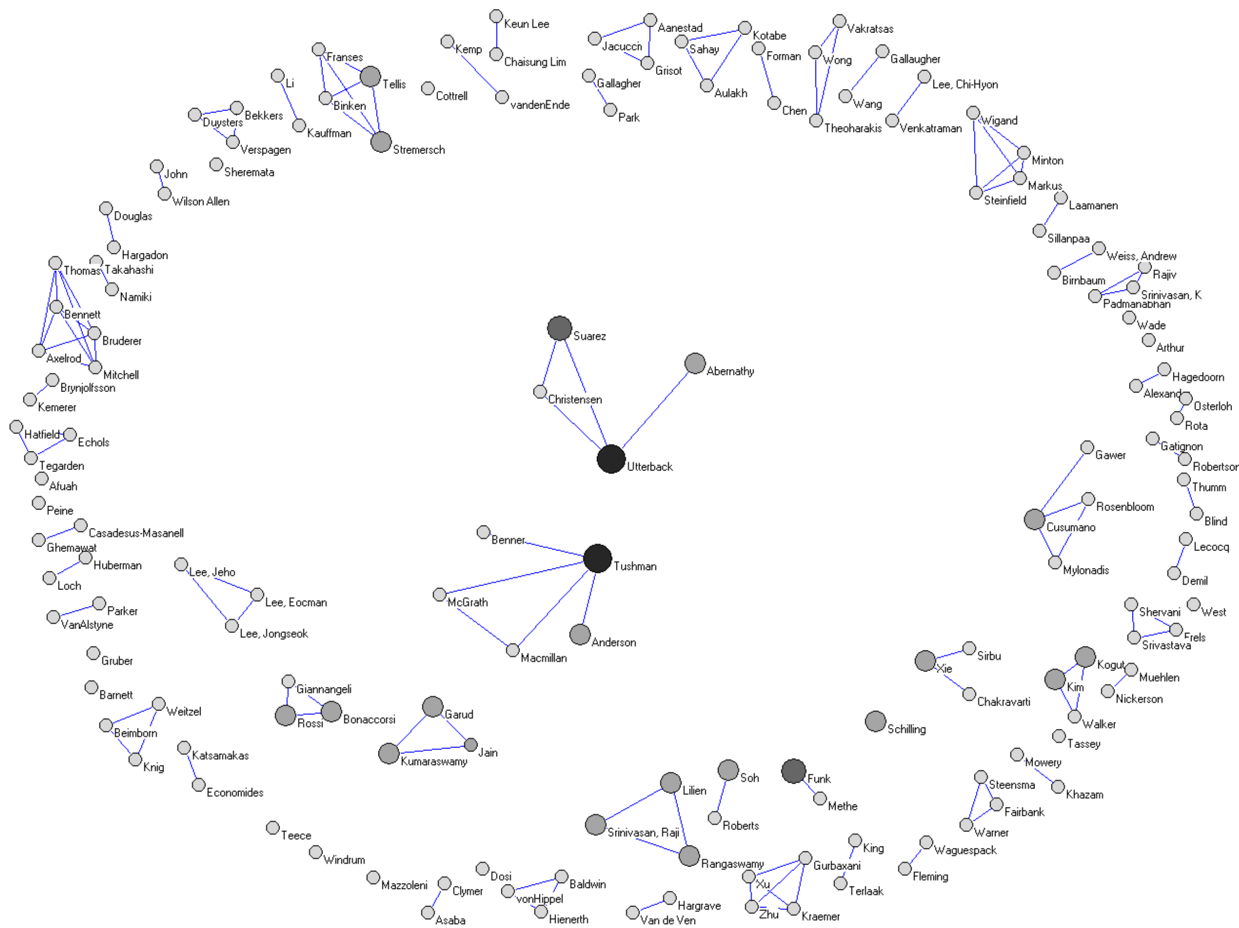


Figure 4. A Summary of Fundamental Arguments from Four Perspectives

MACRO LEVEL

(Populations and communities of organizations)

NATURAL-SELECTION VIEW	COLLECTIVE-ACTION VIEW
Focus of analysis Industry, market category, standards battle ***Flow of logic to explain change*** Technological and socio-economic forces shape technology standards and other macro-level outcomes ***Theoretical lenses*** Grounded theory, network economics, institutional theory, diffusion of innovation, game theory ***Major managerial implications*** Technology industries are characterized by cyclical occurrences of technology change and challenges imposed by emergence of technology standards	***Focus of analysis*** Technological regime, community, ecosystem ***Flow of logic to explain change*** Firms' collective action shapes technology standards and Marco-level outcomes in the industry ***Theoretical lenses*** Grounded theory, network economics, institutional theory, social movements, network analysis ***Major managerial implications*** Firms collectively possess the technology and know-how to advance innovation, therefore they may work together to steer the process for technology standards emerge.
SYSTEM-STRUCTURAL VIEW	**STRATEGIC-CHOICE VIEW**
Focus of analysis Firm ***Flow of logic to explain change*** Technological and socio-economic forces drive firms' adaptation ***Theoretical lenses*** Network economics, contingency theory ***Major managerial implications*** Competitive environment determines firms response to technology standards; firms should design adaptation strategy in light of their organizational strengths.	***Focus of analysis*** Firm ***Flow of logic to explain change*** Firm strategies drive changes within the firm and in the industry ***Theoretical lenses*** Grounded theory, network economics, institutional theory, resource-based view, real option ***Major managerial implications*** A firm's strategy and resources are key factors to determine which technology becomes technology standard.

MICRO LEVEL

(Individual organizations)

DETERMINISTIC ORIENTATION …….VOLUNTARISTIC ORIENTATION

Figure 5. Number of Papers by Theme

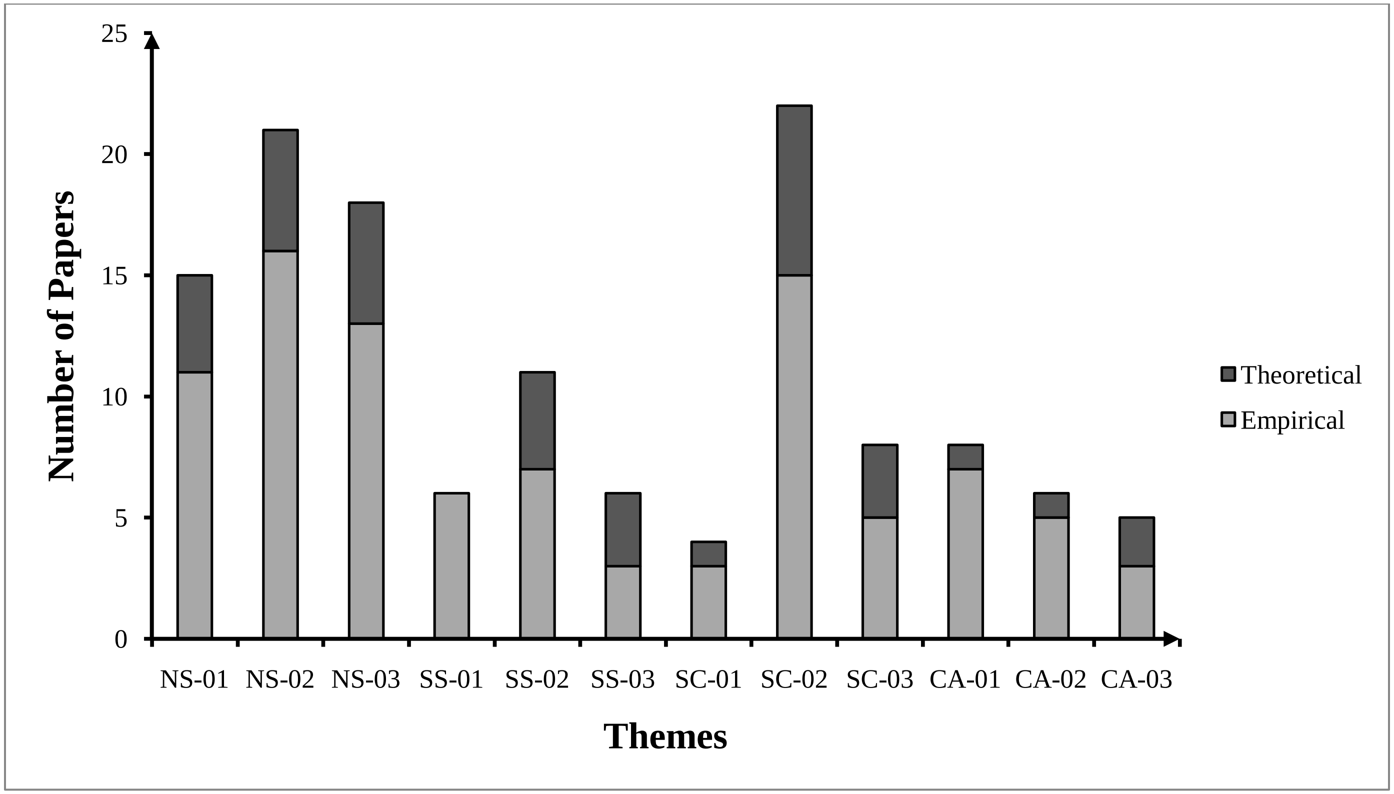
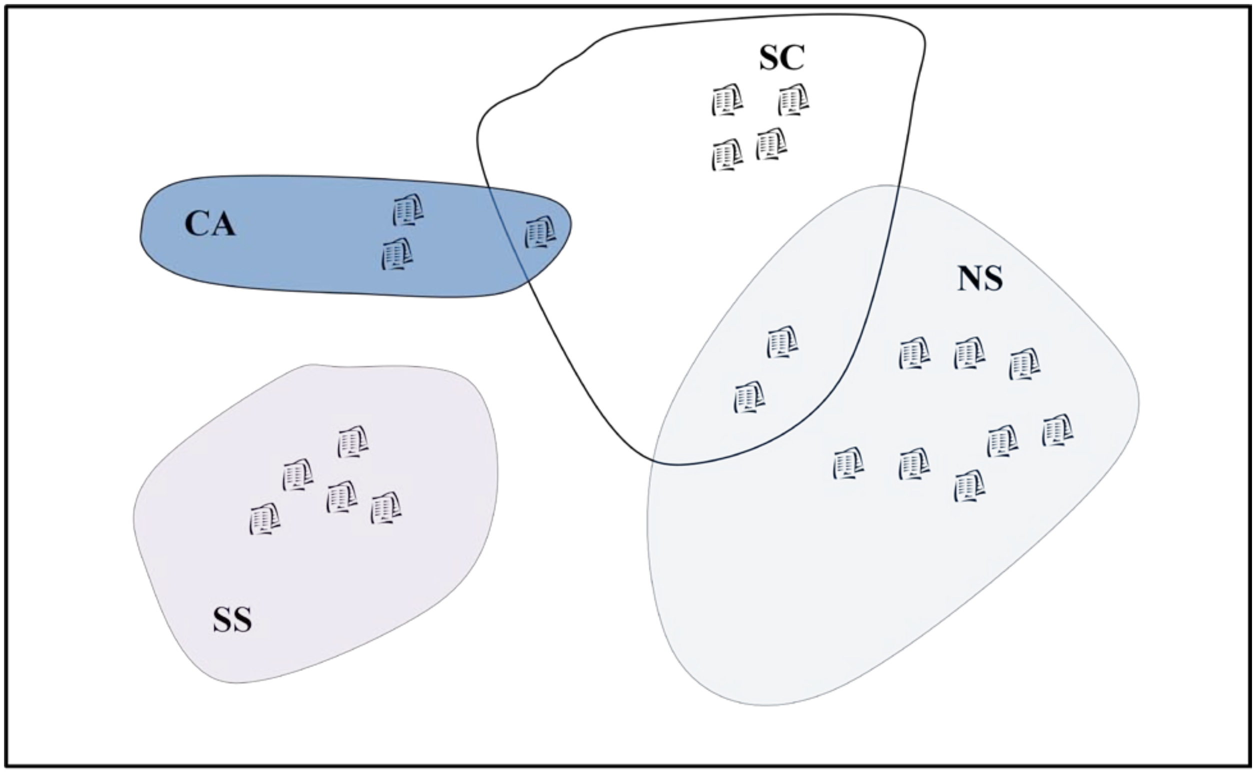
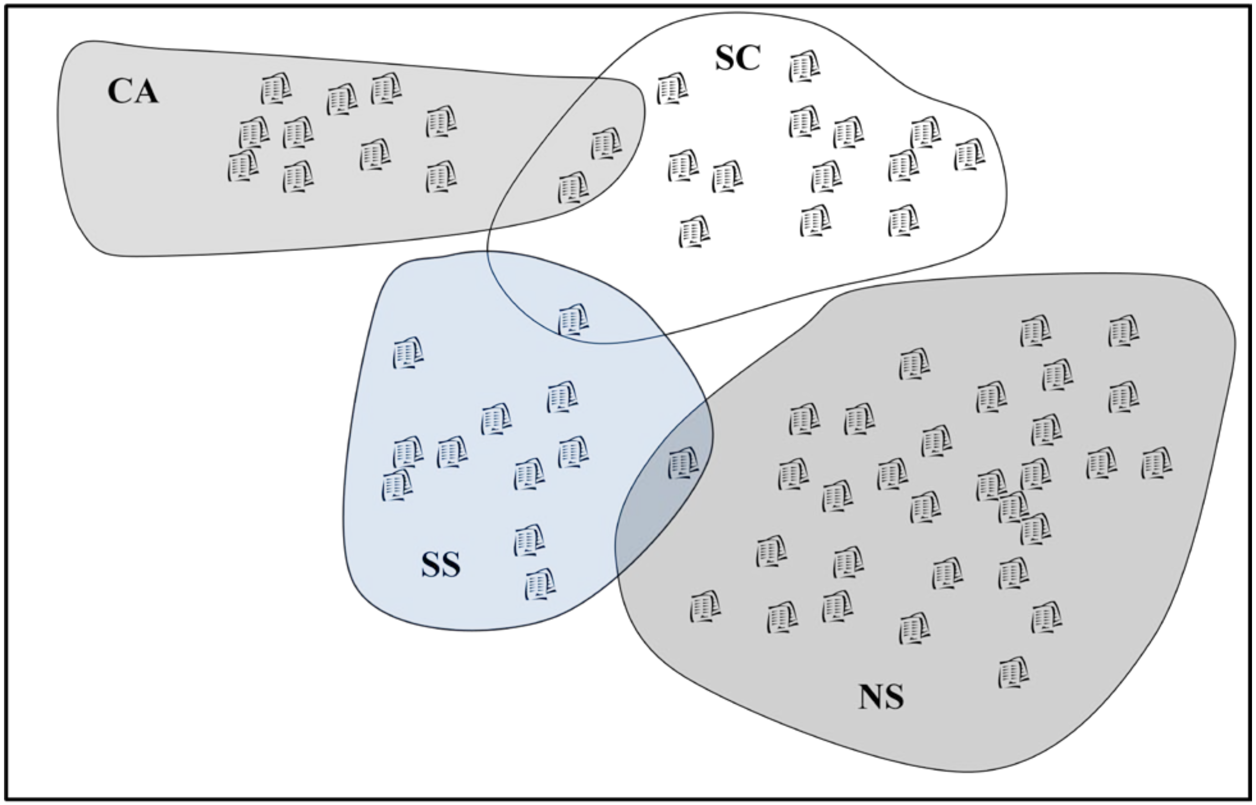


Figure 6. Venn Diagram for Theoretical Papers Based in Different Views



NS - Natural Selection View ; **SS** - System Structural View ; **SC** - Strategic Choice View ; **CA** - Collective Action View

Figure 7. Venn Diagram for Empirical Papers Based in Different Views



NS - Natural Selection View ; **SS** - System Structural View ; **SC** - Strategic Choice View ; **CA** - Collective Action View

Figure 8. A Summary of Findings in the Natural Selection View

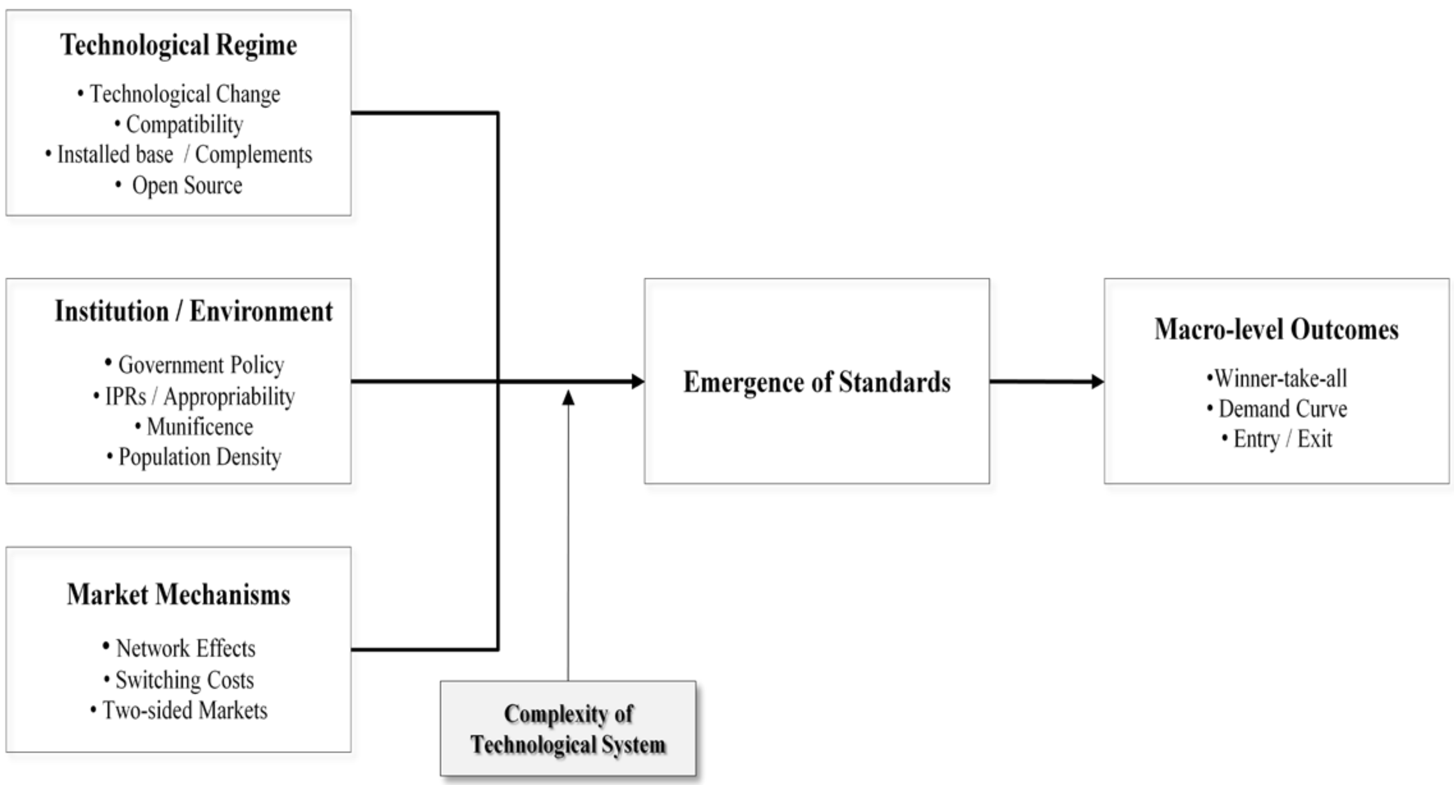


Figure 9. A Summary of Findings in the System Structural View

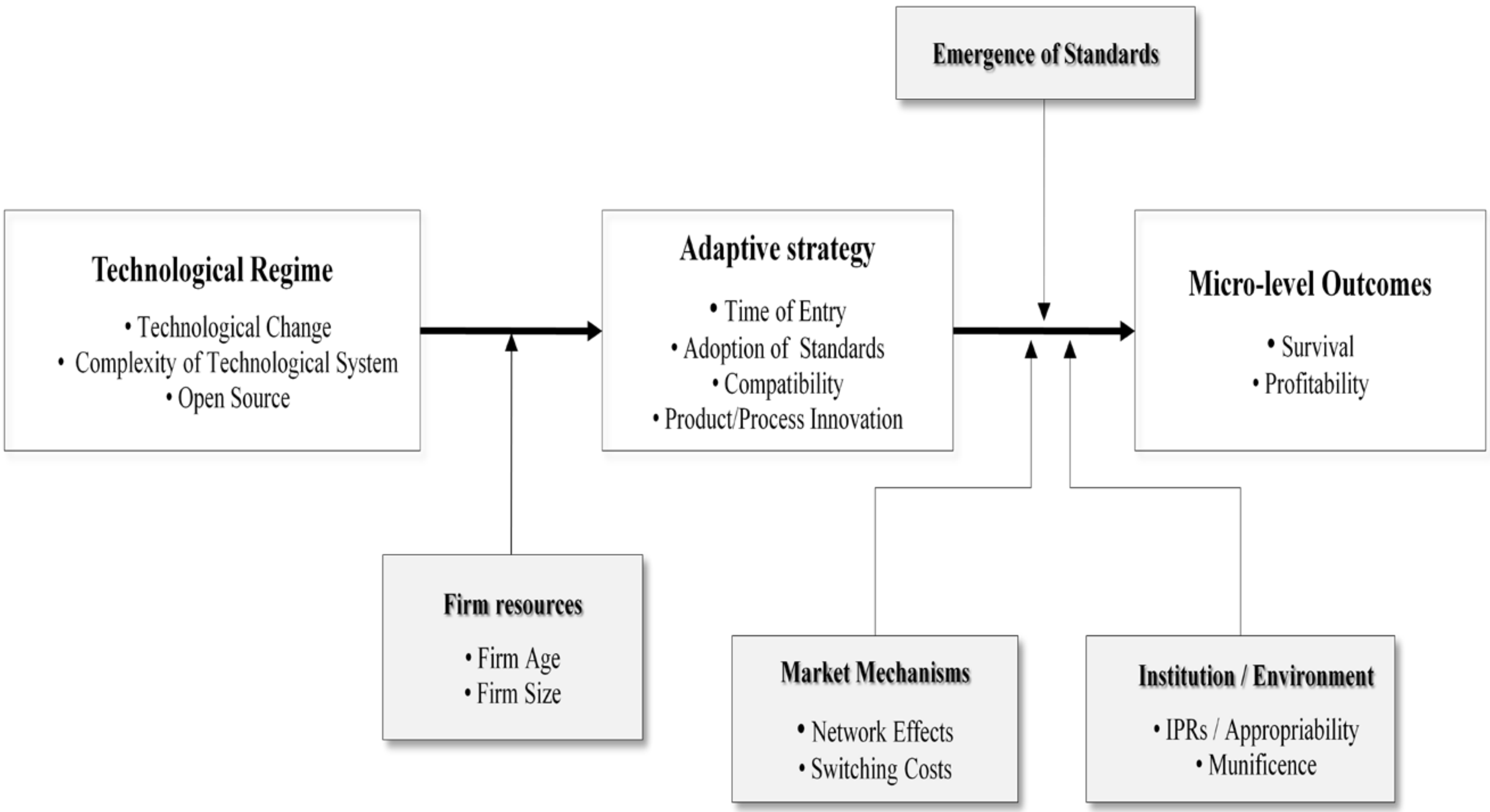


Figure 10. A Summary of Findings in the Strategic Choice View

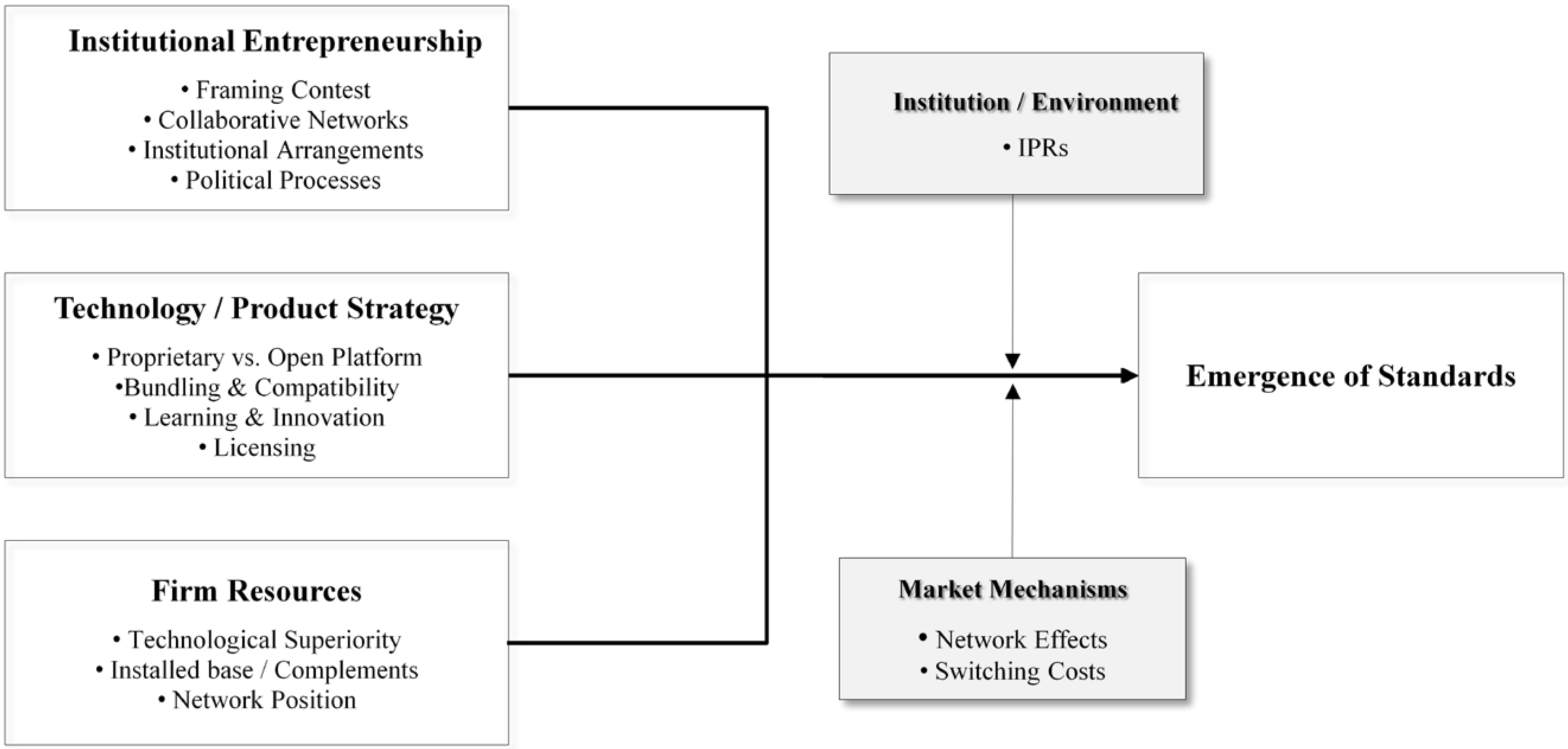


Figure 11. A Summary of Findings in the Collective Action View

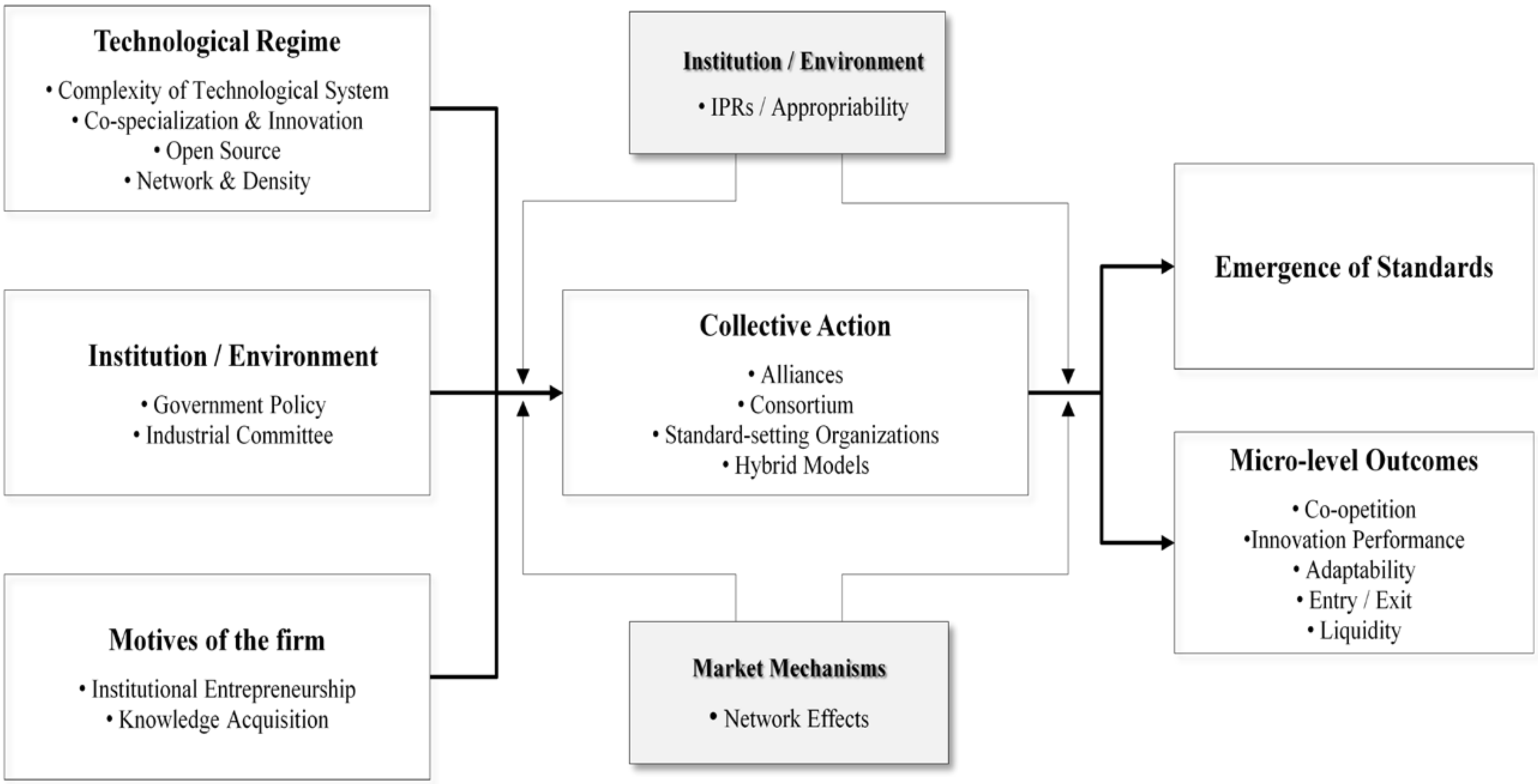


Figure 12. A Conceptual Model of New Firm Survival in Dominance Battle

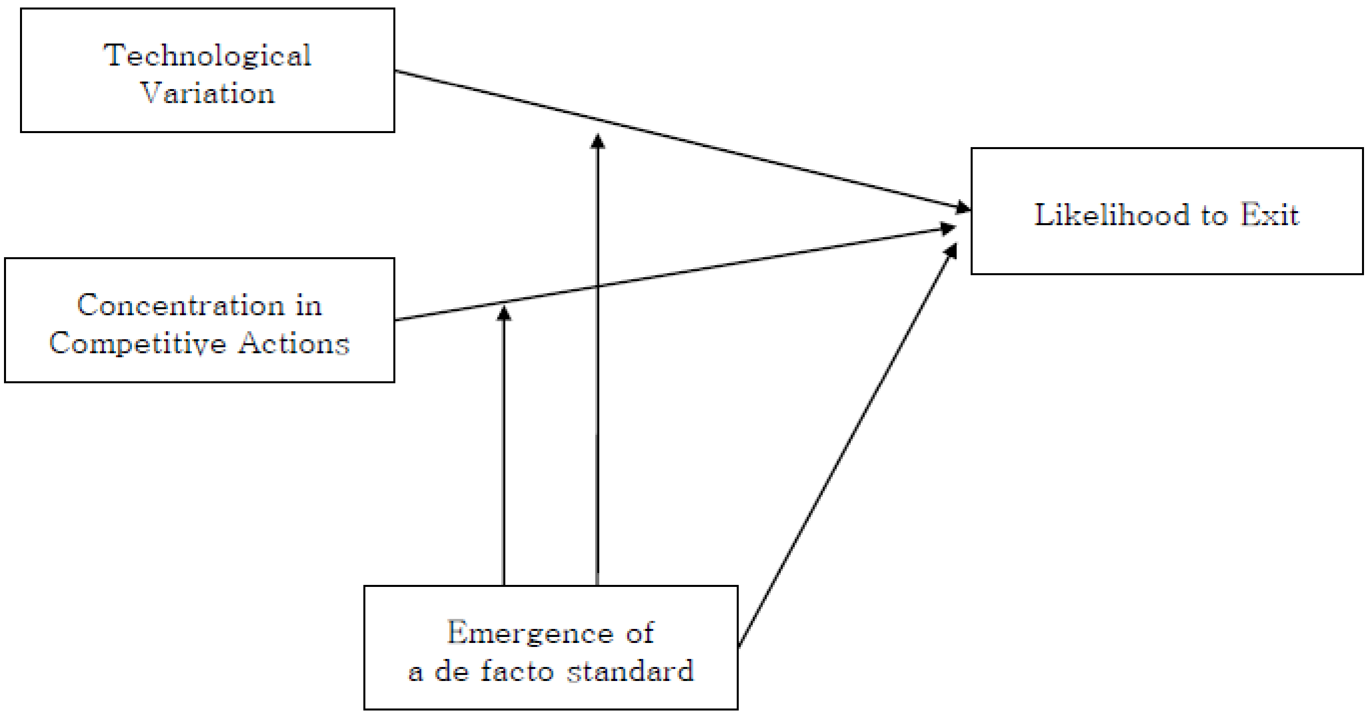


Figure 13. Frequency of Competitive Actions in Different Market Stages

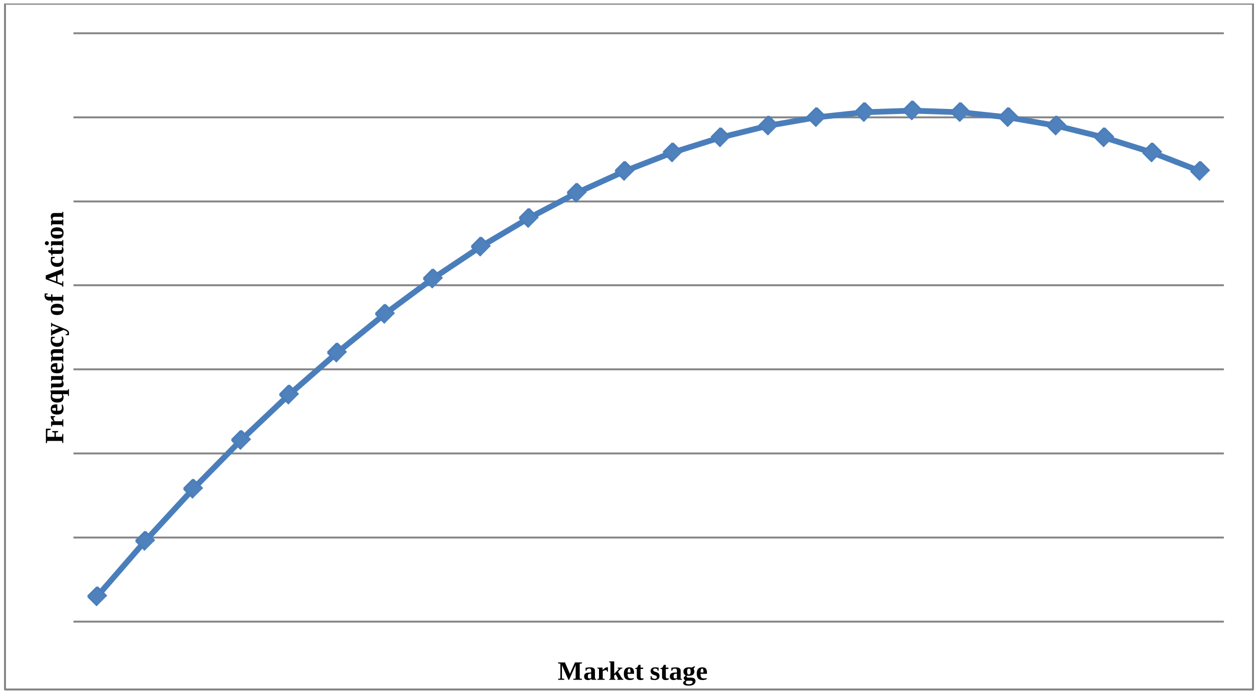


Figure 14. Density and Frequency of Action before and after Dominant Design

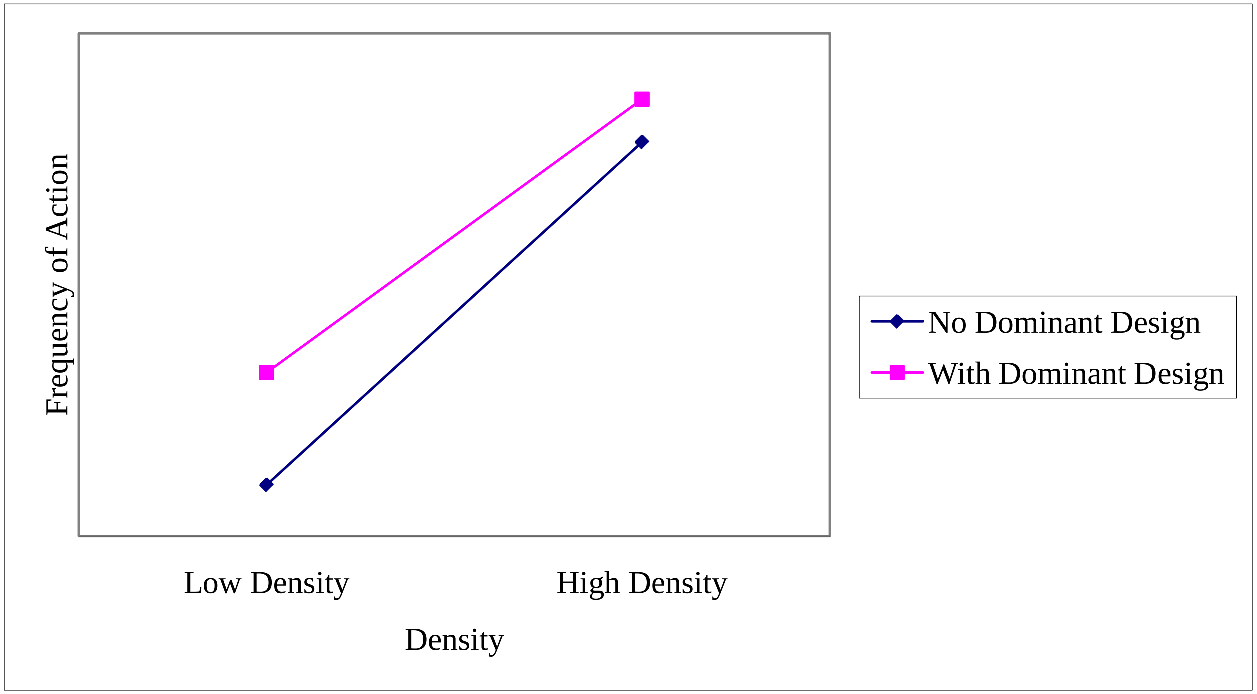
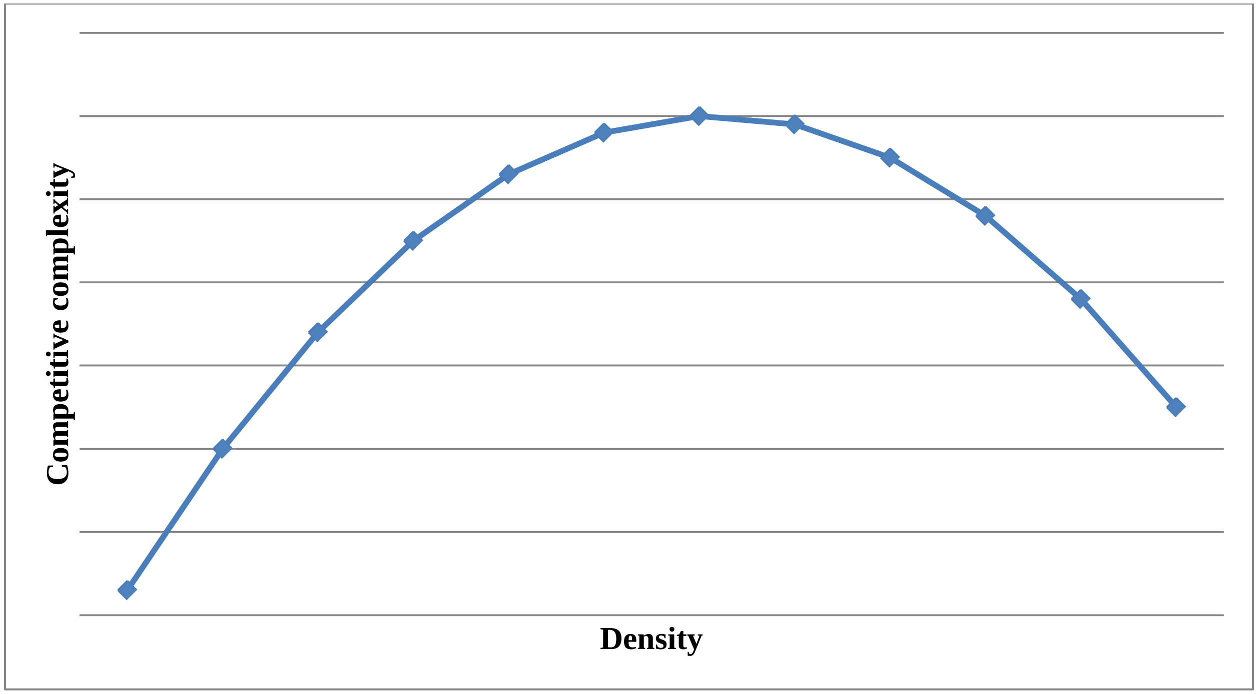


Figure 15. Density and Competitive Complexity



Appendix 1. Summaries of Theoretical Papers

Year	Author	Theme	Type	Unit of analysis	Key Constructs	Findings
Natural Selection View						
1978	Abernathy and Utterback	NS-01	Practitioner	Product line and associated production process taken together	Product versus process innovation;	The article highlights the pattern of innovation in an industry. Product innovation is followed by process innovation.
1982	Dosi	NS-01	Conceptual	Technological paradigms	Technology change, technological discontinuity	Continuous technological changes are often related to progress along a technological trajectory, while discontinuities are associated with the emergence of a new paradigm, whose establishment is often related to new "Schumpeterian" companies.
1986	Robertson & Gatignon	NS-01 NS-02	Conceptual	Innovation	Industry competitiveness, reputation of industry, standards, vertical coordination, resources	The level and speed of diffusion of technological innovation depend on factors such as the competitive intensity, reputation, vertical coordination, R&D, market resources and so on
1989	Weiss and Birnbaum	NS-02 NS-03	Conceptual	Infrastructure supporting technological change	Dominant design, technology change, institutions	A firm's technology strategy requires understanding the dynamics of the technological environment and the level of development of the technological infrastructure.
1996	Arthur	NS-02 NS-03	Practitioner	Industry	Increasing returns, network effects, technology race	Increasing returns to adoption change the way firms compete in network markets.
1999	Loch & Huberman	NS-01 NS-02	Analytical	Technology	Technology diffusion, punctuated equilibra, network externalities, path dependence	The expected time to adoption of a new technology depends on (1) the rate of incremental improvement of the new technology and (2) the system's resistance to switching.
2000	Tassey	NS-03	Practitioner	Standard	Standard, compatibility, market structure	Standards are a form of technical infrastructure with considerable public good. Research policy must include standardization in analyses of technology-based growth.
2006	Economides and Katsamakas	NS-03	Analytical	Technology platform	Technology platforms, network externalities, complements, open source,	Competition in two-sided markets occurs in the combined interaction across platform versus applications markets. The introduction of a third price, a fee that application developers may pay or receive from the platform makes a very significant difference in firms' competitive interactions and the evaluation of the platform applications competitive landscape from the point of view of public policy.

System Structural View						
1995	Xie & Sirbu	SS-02	Analytical	Firm	Pricing, compatibility , network externalities, installed base	A new entrant is better off if its products are compatible with those of the incumbent, especially when demand externalities are strong and the installed base of the incumbent is large
1996	Kotabe, et al.	SS-02 SS-03	Conceptual	Firm	Licensing, standards, network externalities, compatibility, industrial structure	Firms' incensing strategy depends on (1) network externalities and standards, (2) compatibility requirements, industry structure, (4) technology intensity, (5) appropriability regime, (6) complementary assets, and (7) technology development and others.
1997	Padmanabhan, et al.	SS-03	Analytical	Product	Installed base, sequential product introduction, network externalities	Consumer knowledge about network externalities has a significant bearing on the new product strategy. Firm can obtain higher profits with a one-shot new product introduction when consumers are aware of demand externalities. Sequential introduction of products is the optimal strategy when consumers are not informed about the externalities.
2003	Benner and Tushman	SS-02	Conceptual	Firm	Exploration, exploitation, ambidextrous organizations, process innovation	Process management is positively associated with organizational effectiveness during periods of stability or incremental change. However, during eras of ferment and turbulent environments, process management is less conducive to organizational effectiveness.
2004	Sheremata	SS-02 SS-03	Conceptual	Firm	Compatibility, radical innovation, network externalities	The profitability of challengers' compatibility and innovation strategies in network markets depends on the type of innovation, compatibility, intellectual property protection, heterogeneity of consumer preferences, network effects, switching costs, R&D fixed costs, technological uncertainty.
Strategic Choice View						
1990	Wilson, et al.	SC-02	Analytical	Bundling options	Industrial systems, modularity, bundling	Firms' choice of bundling drives the growth of market size. Growth is the key to making the unbundling option attractive.
1992	Mcgrath, et al.	SC-03 SC-02	Conceptual	Firm	Top management team, dominant design, technological discontinuity	A dominant design is driven by strategic decisions by top managers of interacting firms and practitioner communities.
1998	Schilling	SC-02 SC-03	Conceptual	Firm	Learning, installed base, complementary products, standards	In the competition for technological dominance, firms' likelihood of technological lockout depends on interaction between (1) firms' innovation strategy and resources (including complementary products) and (2) external conditions such as network effects and entry barriers.

2002	Cusumano and Gawer	SC-01 SC-02	Practitioner	Firm	Platform leader, complementors, standards war	Platform leadership can create an industry ecosystem greater than the sum of participating firms.
Collective Action View						
2006	Hargrave & Van De Ven	CA-01 CA-03	Conceptual	Technological community	Institutional innovation, social movement, standards, collective action	The paper proposes a model to link the converging perspectives from the technology innovation management and social movements literature, viewing institutional change as a dialectical process in which partisan actors espousing conflicting views confront each other and engage in political behaviors to create and change institutions.
2007	Osterloh & Rota	CA-02	Conceptual	Open source innovation	Open source, Licensing, Collective invention;	OSS enhances the collective invention model by generating a low-cost situation in contributing to public goods. The institutional innovation of OSS licenses maintains voluntary donations of intrinsically motivated contributors.
Studies Based in Multiple Views						
2004	Suarez	NS-02 SC-02 SC-03	Conceptual	Firm	Technological innovation, open source, complementors, network externalities	The paper highlights several key firm- and environment-level factors affecting the outcome of a technology battle, positing that the relative importance of each factor will vary depending on technological phase.
2005	Parker and Van Alstyne	NS-03 SC-02	Analytical	Firm	Complementary products, network externalities, two-sided markets, free products	Even in the absence of competition, a firm can rationally invest in a product it intends to give away into perpetuity. Second, there exist distinct markets for content providers and end consumers and either can be a candidate for a free good. Third, product coupling across markets can increase consumer welfare even as it increases firm profits
2007	Teece	SC-02 CA-03	Conceptual	Firm	Co-specialization, ecosystem, dominant design	Enterprises with strong dynamic capabilities shape ecosystems through innovation and through collaboration with other enterprises, entities, and institutions.

Appendix 2. Summaries of Empirical Papers

Year	Author	Theme	Sample	Method	Findings
Natural Selection view					
1986	Tushman &Anderson	NS-01 NS-03	Cement, airline, minicomputer industries, 11 technological discontinuities	Frequency table / Archival	Technology evolution follows long periods of incremental change punctuated by rare innovations that radically improve the state of art.
1990	Anderson &Tushman	NS-01 NS-03	Cement, minicomputer, glass industries (glass industry has three sub-segments), 12 dominant designs, 16 technological discontinuities	Frequency table / Archival	The paper provides a punctuated equilibrium model of technological change. It also provides implications on the link between environmental / organizational factors and technological change / dominant designs.
1990	Barnett	NS-02	986 telephone companies in Pennsylvania and Iowa from 1879-1934	Event history analysis / Archival	Technological change does not necessarily favor technically advanced organizations; instead, mutualism plays a key role as long as technology is standardized.
1990	Henderson & Clark	NS-01	The semiconductor photolithographic alignment equipment industry	Case study / Archival	Architectural innovation destroys the usefulness of the architectural knowledge of established firms, and since architectural innovation is embedded in the structure and information-processing procedures of established organizations, this destruction is difficult for firms to recognize and hard to correct.
1995	Wade	NS-02 NS-03	20 communities / quarterly data from 1971-1989	Poisson event model / Survey / Archival	The paper highlighted the importance of community-level framework in understanding the bandwagon phenomenon in industries characterized by network externalities and increasing returns.
1996	Brynjolfsson & Kemerer	NS-02	93 different product observations in commercial spreadsheet industry from 1987 to 1991	Hedonic regression / Archival	Network externalities significantly increase the price of spreadsheet products. Products adhering to the dominant standard commands prices which are higher.
1996	Wade	NS-03	35 firms / quarterly data from 1971-1989	Poisson regression/ Survey / Archival	Microprocessors were likely to be introduced by first-time sponsors; and entry rate of later sponsors and supporters follows density-dependence model.
1997	Mazzoleni	NS-02	US and Japanese machine tool industry	Descriptive stats/ Archival	The diffusion of new technological designs is influenced by the path-dependence engendered by the learning processes.
1999	Van den Ende &Kemp	NS-01 NS-02	Digital computer industry	Case study/ Archival	Digital computer regime is created through a process of transformation conceptualized as a regime shift: a change in rules that underpin technical change, which guides innovative activity and output into particular directions.
2000	Gruber	NS-03	Chip industry with four submarket data from 1984–1997	Time-series analysis / Archival	This paper looks at the role of product standards in determining the evolution of market structure in semiconductors. The paper suggests that product standards, along with learning-by-doing effects, lead to market concentration and persistence of leadership in

					product innovation.
2001	Lee and Lim	NS-01	Selected industries in Korea, including the D-RAM, automobile, mobile phone, consumer electronics, personal computer, and machine tool industries	Case study / Archival	The process of technological catching-up is an outcome of a complex interplay of in-house R&D, the government, the modes of technology transfer, market conditions, absorption capacity, and the nature of the technology or knowledge itself. A path-following or skipping catching-up is more likely to happen largely by private initiatives in industries, whereas a path-creating catching-up is more likely to happen by public–private collaboration.
2002	Bekkers, et al.	NS-02 NS-03	GSM in the global market	Case study / Archival	The timing of the emergence of strong network positions is linked to IPRs. The relationship between market power and IPRs and network centrality is positive with some notable exceptions.
2002	Gallaugher and Wang	NS-03	321 observations based on monthly data in Web server industry from August 1995 - February 1997	Hedonic pricing model / Archival	Market share is positively linked to price in network markets. A network market is two-sided and firms may capture market share for one product and enjoy benefits in terms of both market share and price for the complement.
2003	Frels, et al.	NS-03	237 usable survey from the initial attempt to 3000 senior computing executives at large firms in the United States	Structure equation model / Survey	Network-based value is significantly and positively associated with the resources allocated by customers to competing products.
2003	Takahashi & Namiki	NS-02 NS-03	Personal computing industry since 1980s	Case study / Archival	This paper raises interrelated issues about innovation: (1) the path-dependent nature of innovation, especially that due to network externalities, (2) the balance between property rights and antitrust laws, and (3) the relevance of government intervention in these areas.
2004	Funk	NS-01	Mobile phone industry from 1981-1999	Case study / Archival	Klepper's model of the product life cycle theory in combination with the concept of product line management provides a better explanation for the evolution of competition in the mobile phone industry than the traditional product life cycle model.
2006	Casadesus-Masanell &Ghemawat	NS-02	Shipments of Linux versus Microsoft server OS in 45 countries in 2001	Case study, OLS regression / Archival	Forward-looking buyers tip market outcomes toward Open Sources software and away from proprietary software.
2006	Chakravarti & Xie	NS-02	181 undergraduate students participated in a computer-based experiment	Binomial logistic regression / Experiment	Consumers are less likely to adopt a new product when there is ongoing standards competition. The impact of information about the relative performance of a product on consumers' adoption decisions is stronger in markets with standards competition than in those without it.
2006	Chen & Forman	NS-02	22,000 establishments surveyed by Harte Hanks Market Intelligence	Multinomial Logit model / Survey	The presence of switching costs can lead to inefficient adoption of new information technology and vendors may be able to influence the speed of technology adoption.

2006	Hanseth, et al.	NS-01 NS-02	Field study (interviews, observations) from 1996 - 2001	Case study /Interview/Observation	Information system standards are a socio-technically complex issue which generates reflexive processes that undermine standardization aims. It is useful to bring in a theoretical interpretation of standardization complexity by using ideas from complexity theory and the theory of reflexive modernization.
2006	Baldwin, et al.	NS-01	NA	Simulation	The paper illustrates the path of how user innovations are transformed into commercial products.
2006	Lecocq and Demil	NS-03	193 active U.S. companies in RPG sector between the 2-year periods of 1998–99 and 2000–01	ANOVA / Archival	The introduction of an open system in a low-tech industry increases the number of new entrants into that industry. In a low-tech industry, new entrants adopt an open system more readily than incumbents. The introduction and diffusion of an open system into a low-tech industry is followed by a decrease in the average size of firms in that industry.
2006	Lee et al	NS-01 NS-03	NA	Simulation /Experiment	The validity of winner-take-all hypothesis depends on how customers interact with one another (e.g., if they exchange advice or files). In some interaction networks, customers influenced by their acquaintances may adopt a lagging technology even when a lead technology has built a large installed' base. The presence of such a local bias facilitates the persistence of incompatibilities. When local bias cannot be sustained in other interaction networks, one technology corners the market. Overemphasizing the installed base, while ignoring network structure, could mislead practitioners.
2006	Nickerson & Muehlen	NS-01	505 participants in standard-making activities across nine standard institutions, 63 meetings and 22 standards-related publications in Web Services Choreography	Case study, link analysis / Archival	An ecological approach will apply to inventions that have been incubated, such as the Internet. Changes to institutional Internet governance, particularly to the bylaws of standards bodies, can have drastic and unintended effects that will reshape the standard-making ecology
2006	Srinivasan, et al.	NS-02	63 office products and consumer durables from different sources: articles published in scholarly journals, books, and online business databases	Split-population hazard model / Archival	A dominant design is more likely to emerge with weak appropriability, weak network effects, low product radicalness, and high research-and-development intensity; Dominant designs that emerge are likely to emerge sooner in product categories in which there is weak appropriability, there are a large number of firms in the value net, the standards are set by a de facto process, and there is low product radicalness.
2006	Weitzel, et al.	NS-02	NA	Simulation	Network topology and density have a strong impact on standard diffusion and that the tendency toward monopoly in such market occurs less frequently than expected.
2007	Stremersch, et al.	NS-02	Consumer electronics in different historical time periods (1946-2005)	Takeoff analysis, time series analysis / Archival	Indirect network effects are often weaker than expected from prior literature. In most markets examined, hardware sales "lead" software availability, whereas the reverse almost never happens, contrary to existing beliefs.
2007	Terlaak and King	NS-03	13,710 U.S. manufacturing facilities from 178 industries adopting ISO 9000 from 1988 to 1999	Logistic regression / Archival	When the value of adoption increases with organizational size, smaller adopters have such disproportionate influence because they allow observers to infer that adoption will be profitable for their own organization. Alternative information sources moderate the influence of smaller adopters.

2007	Theoharakis, et al.	NS-02	10,412 LAN related market stories for the period 1981–2000	Event history analysis / Archival	Technology and product availability have differential effects on the adoption of competing standards. The significance of these effects depends on the technology's order of entry. High-tech product managers should make strategic use of market-level information by appropriately focusing the content of their communications.
2008	Peine	NS-01 NS-02	Smart Home systems	Case study	Technology systems may involve distinct paradigms that jointly shape the innovation process, creating challenges for the coordination of innovation.
System Structural View					
1975	Utterback & Abernathy	SS-01	Five industries, 120 firms, 567 innovations / data provided by the study of Myers and Marquis (1967)	Frequency table / Archival	The pattern of innovation within a firm changes systematically from product to process innovation, as predetermined by technological cycle.
1995	Suarez &Utterback	SS-01	All firms from automobile, typewriter, transistor, calculator, television and picture tube industries in different time periods	Event history analysis / Archival	The paper provided evidence that early entry before a dominant design is associated with higher chance for survival.
1998	Christensen, et al.	SS-01 SS-02	Every firm who introduced disk drive worldwide 1976 - 1979	Event history analysis / Archival / Interviews	First mover advantage is not important in the rigid disk industry; instead, the entry-window tied to the emergence of dominant design is crucial for firm survival.
1999	Tegarden, et al.	SS-01 SS-02	463 PC manufacturers from 1975-1991	Event history analysis / Archival	Firms are not doomed even if they choose the wrong design initially. For both earlier and later entrants, switching to dominant design increases their survival.
2001	Afuah	SS-02	81 RISC computer workstation projects by 25 workstation makers between 1986 and 1993	Panel Random-Effects/ Archival	Following a competence-destroying technological change, firms vertically integrated to new technology will perform better than those that are not. Firms vertically integrated into the old technology will perform worse than those that had not been.
2004	Srinivasan, et al.	SS-02 SS-03	45 office products and consumer durables introduced after the second World War (time period over 50 years)	Event history analysis / Archival	Network externalities have a negative main effect on the survival duration of pioneers; however, for more radical products and for technologically intense products, increases in network externalities are associated with increased survival duration. In addition, the larger the pioneer, the more network externalities increase its survival duration, whereas incumbent pioneers experience a decrease in survival duration compared with non-incumbents.
2004	Venkatraman &Lee	SS-02 SS-03	2,815 releases (links) in 96 months from 1995 through December 2002	Multinomial Logit models / Archival	The developers' choices to launch games for particular game consoles depend on network structure (density overlap and embeddedness) and technology characteristics of a platform (dominance and newness).
2005	Kauffman & Li	SS-02	Firm-level decision-making simulation for technology adoption	Simulation / Experiment	A technology adopter should defer its investment until one technology's probability to win out in the marketplace and achieve critical mass reaches a critical threshold.

2006	Zhu, et al.	SS-03	1,394 respondents from a large-scale international survey conducted in 10 economies during February, March, and April, 2002.	Structural equation modeling / Survey	There are significant impacts of network effects on open-standard IOS adoption. Adoption costs are a significant barrier to open standard IOS adoption, but EDI users and nonusers treat this very differently: EDI users are much more sensitive to the costs of switching to the new standard.
2006	Bonaccorsi, et al.	SS-02	146 Italian software firms	Logit model / Survey	Firms tend to follow a hybrid business model in the face of open source. However, the stability of the hybrid models depends on the evolution of the industry.
Strategic Choice View					
1992	Cusumano, et al.	SC-02 SC-03	Video Cassette recording industry / two competing firms	Historical analysis / Archival	The success of VHS (Video Home System), introduced in 1976 by the Victor Company of Japan (Japan Victor or JVC), demonstrates how a firm may successfully diffuse and standardize its technological in the presence of a powerful rival — in this case, the Betamax, introduced in 1975 by the Sony Corporation.Despite being first to the home market, the Beta format fell behind the VHS in market share during 1978 and declined thereafter. This mass consumer market with network effects took years to unfold and was largely shaped by the strategic maneuvering of the VHS producers.
1993	Garud &Kumaraswamy	SC-02	Work station industry / Sun Microsystems	Historical analysis / Archival	Firms' choices of complementary products, compatibility between products, and access to technical knowledge are key issues to establish standards.
1994	Khazam & Mowery	SC-02	Microprocessor industry / several computer manufacturers	Historical analysis / Archival	The history of RISC suggests that firms can pursue strategies that aid in the establishment of their products as dominant designs. In the case of RISC, licensing has assumed particular significance because of the important complementarities between hardware and applications software, which results in network externalities.
2001	Hargadon and Douglas	SC-01 SC-02	Edison's introduction of electric lighting	Historical case study / Archival	Robust design explains how Edison's organization gained acceptance for an innovation that would ultimately displace the existing institutions of the gas industry. Electric lighting systems gained recognition, at least in part because they were framed early on in familiar terms that called to mind existing gas lights.
2002	Gallagher and Park	SC-01 SC-02	U.S. home video game industry since 1976 - 2002	Historical analysis / Archival	The paper confirms the value of traditional strategic management in a network based industry, such as technological innovation, building entry barriers, protecting firm-specific assets, in winning network-based competition.
2002	Garud, et al.	SC-01 SC-02	Sun Microsystems' Java	Case study / Archival	Firms may use institutional entrepreneurship to establish technology standards. Standardization is an institutionalization process that is inherently unstable and politicized.
2002	Schilling	SC-02 SC-03	89 cases from 14 product categories	Logistic regression / Archival / Survey / Interview	Besides installed base and the availability of complementary goods, a firm's learning orientation and timing of entry also play significant roles in achieving technological success.
2002	Stremersch and Tellis*	SC-02	NA	NA	There are several types of bundling firms can use to generate competitive advantage and performance. However, the effectiveness of this strategy depends on market conditions.

2003	Funk	SC-02	NTT Docomo and its four phone suppliers in Japanese cellular phone market from 1993 and 1997	Case study / Archival / Interview	NTT Docomo and its suppliers heavily influenced the resulting dominant design through their information advantages. However, installed base does not appear to play the same role in the determination of dominant designs (at least in this case) as it does in standards.
2003	Soh & Roberts	SC-02	150 firms and 319 alliances in the US data communications industry from 1985 to 1996	Network analysis / Archival	During eras of incremental change, if established firms with peripheral subsystems are able to adopt early new technologies with implication for compatibility, they may become more central in the technology collaboration network.
2004	Windrum	SC-02	The browser wars (1995-1999)	Case study / Archival	Cross-product externalities played an important role in determining the final outcome, namely, the winner of the browser wars (technology standard).
2006	Warner, et al.	SC-02 SC-03	163 acquisitions in IT Industry from 1995-2000	Logit model / Archival	Firms competing in standardizing markets may choose the acquisition timing to obtain technical knowledge and thus to keep growth option open.
2008	Clymer and Asaba	SC-02 SC-03	Seven “dominant design manufacturers” in the consumer ink-jet printer market	OLS regression / Archival	Dominant design can occur at the firm level and can be quantitatively represented by the number of ink-jet patents in nine categories of a matrix that distinguishes patents according to method of implementation and type of module. Further, we find that annual firm ink-jet revenue from 1990 through 2000 is positively correlated with a balanced dispersion of patents across the nine categories. Results suggest that higher revenues will accrue to firms in integrated industries when resources are balanced among important sub-technologies in the dominant design.
Collective Action View					
1994	Cottrell	CA-01	US and Japanese microcomputer markets	Case study/ Archival	Public policy efforts to address problems that arise from multiple standards have proven less successful in the minicomputer software industry. A comparison of the US versus Japanese microcomputer software industries suggests that while Japanese firms may lag in the near term, the problems posed by multiple standards may well aid in the long-term adaptability and performance of the Japanese industry. In contrast, the US industry, while firms may benefit from the existence of a single dominant standard, the industry has evidenced difficulty moving to new standards.
1995	Axelrod, et al.	CA-03	Nine firms developing Unix workstations	ANOVA / Archival	Firms may balance the conflict between enjoying the benefits of standardization and incurring the problems of associating with close competitors.
1995	Kogut, et al.	CA-01 CA-02	126 start-ups from semiconductor industries from 1977 and 1989	Poisson regression/ Archival	Higher density of cooperation in the subfield should lead to more start-up entrants in the subsequent time period. In addition, the more centralized is the subfield network, the more start-ups should enter the subfield in the subsequent time period.
2001	Funk and Methe	CA-01	9 Japanese, 3 US, 6 European firms in mobile communication industry in Japan, US and Europe	Multiple case studies / Interviews	Governments can influence the installed base for systems in the mobile and communication industry. The choice of a single standard increases the forecast for the standard's domestic installed base, causing other countries to adopt the same standard.
2001	Hagedoorn, et al.	CA-02	IBM and Apple alliances from 1980–1996	Case study / Archival / Interview	Technology partnering between proponents of competing basic designs can only materialize several years after the DOS-based design of IBM and Microsoft had become dominant.

2003	Bonaccorsi & Rossi	CA-02 CA-03	A simulated population of heterogeneous interacting agents in software industry	Simulation	Open Source systems diffused in environments dominated by proprietary standards. The movement took off through the activity of a community that did not follow profit motivations. A hierarchical co-ordination emerged without proprietary rights.
2006	Markus, et al.	CA-01 CA-02	VIS standardization in the U.S. residential mortgage industry	Case study / Interviews / Observation	VIS standardization involves two linked collective action dilemmas — standards development and standards diffusion — with different characteristics, such that a solution to the first may fail to resolve the second. Successful VIS standards consortia must encompass heterogeneous groups of user organizations and IT vendors without fragmenting. Some tactics successfully can be used to solve the collective action dilemma of VIS standardization — e.g., governance mechanisms and policies about intellectual property protection.
2004	Blind &Thumm	CA-01	149 European companies, survey data derived from the study 'Interaction of standardization and intellectual property rights'	Regression / Factor analysis / Survey	This paper analyses the relationship between strategies to protect intellectual property rights and their impact on the likelihood of joining formal standardization processes. Companies at the leading edge are often in such a strong position that they do not need the support of standards to market their products. The results suggest that the higher the patent intensities of companies, the lower is their tendency to join standardization processes.
2009	Sillanpää and Laamanen	CA-03	Television broadcasting technology in U.K.	Case study / Archival / Interview	By building on an analysis of the digital television launch in the United Kingdom, this paper suggests that network externalities intensify competition and cause strong negative feedback effects to emerge. Actions aimed at improving one's position are systematically imitated and pre-emptied. Pressure builds up in the business system, and only when the weakest firms exit, the positive feedback effects are unleashed in their full magnitude. The findings contribute to an improved understanding of institutional dynamics in new technology introduction.
2009	Soh	CA-01	49 firms that competed for two technology standards in the U.S. local area network industry from 1989 to 1996	Negative binomial regression / Archival	Firms can benefit from maneuvering through alliance networks that consist of partners and rivals that prefer a competing standard. Central firms with high ego network density, coupled with a strategic intent to acquire and share knowledge broadly within the technological community, achieve better innovation performance
Studies Based in Multiple Views					
1993	Utterback & Suarez	NS-03 SS-01	Firms from automobile, typewriter, transistor, calculator, television and picture tube industries from at different time periods	Descriptive stats/ Archival	Driving forces based on technological change determine the form and level of competition, the attractiveness of entry and ultimately the structure of an industry. The life chance of organizations in technology industries depends on their ability of adaptation.
1996	Kim and Kogut	SS-01 SC-03	180 startup firms founded between 1977 and 1989 in semiconductor industry	Regression / Archival	The pattern of diversification of firms reflects the evolutionary branching of underlying technologies. A firm with experience in a platform technology is more likely to diversify into the exploration and generation of new markets than a firm that has developed narrowly based skills. However, the pattern and timing of entry into a subfield are related positively to the growth of the market.

2003	West	SC-02 CA-02	Apple Computer, IBM and Sun Microsystems, computer industry	Case study / Archival	Proprietary platforms may use hybrid strategies to generate competitive advantage in standardization processes. Platforms may explore advantages of open source strategy but at the same time control the technology to remain differentiation. The effectiveness of this strategy, however, depends on the industrial conditions.
2009	Waguespack and Fleming	SC-02 CA-01	1,141 US venture-backed start-ups in Internet communications / data communications industries	Even history analysis / Survey / Interview / Archival	A start-up's participation in open source standards might increase its chances of a liquidity event (IPO) in four ways: gaining endorsement of the startup's technology standard, openly developing the startup's technology within the community, attending physical meetings of the community, and having startup members elected to leadership positions. Examination of venture-funded startups in the networking/ data communications industry sectors reveals that those startups that participate in an open standards community have a greater likelihood of an initial public offering or acquisition.

*We considered this paper as empirical because it offers descriptive statistics.

Curriculum Vitae

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EDUCATION

Ph.D. Management, Drexel University (expected, June 2011)
LeBow College of Business, Drexel University, Philadelphia, PA
Major: Strategic Management and Entrepreneurship

M.A. English, Sichuan University (2004)
Chengdu, Sichuan, P.R. China

B. S. Engineering, Chengdu University (1994)
Chengdu, Sichuan, P.R. China

RESEARCH INTERESTS

Firm strategy and entrepreneurship in technology change
Competitive dynamics in high-technology industries
Dominant designs and standardization

RESEARCH

Dissertation

Title: *Technological Standards, Competitive Dynamics, and Entrepreneurship*
(Proposal Defended on May 14, 2010)

Essay One: Research on Technological Standards: A Comprehensive Literature Review (finished for submission).

Essay Two: De facto Standards, Platform Owners, and Competitive Dynamics (data collection).

Essay Three: Technology Turbulence, de facto Standards and Strategy of de novo Platform Owners: A Survival Analysis (Complete).

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Conference Presentations

Chen, T. & Narayanan, V.K. Nascent Market Categories, Dominant Designs and Survival of New Member Firms. To be presented at *2011 Academy of Management Meeting*, forthcoming.

Yang, Y., Chen, T. & Pan, L. Survival of New Technology Companies in Ecosystem Venturing through Corporate Venture Capital Investments. Paper presented at the *2010 Southern Management Association Meeting,* October 28-30, at the TradeWinds Island, Florida.

Chen, T. & Narayanan, V.K. Technology Turbulence, Dominant Design and Strategy of de novo Platform Leaders. Paper presented at *2010 Academy of Management Meeting*, August 6-10, in Montreal, Canada.

Narayanan, V.K. & Chen, T. Competition for Technological Standards: Accomplishment and Challenges. Paper presented at *The British Academy of Management Conference 2010*, 14-16 September , at the University of Sheffield.

Yang, Y., Chen, T. & Pan, L. How Do New Technology Companies Survive in Ecosystem Venturing? Paper to be presented at the *Third Annual Conference of the Academy of Innovation and Entrepreneurship,* during July 9th-11th, 2010, at Tsinghua University, Beijing, China.

Zane, L. J., Chen, T. & De Carolis, D. (2009). A Model of Entrepreneurial Competitive Moves: The Influence of Industry Context and Individual Factors. Paper presented at the *29th Annual International Conference (2009) of Strategic Management Society*

Chen, T., Zane, L.J., Yamada, H., & Kurokawa, S. (2009). Firms' Strategic Choice in Standards War: A Historical Analysis of 78 Cases. Paper presented at *2009 Academy of Management Annual Meeting,* August 7-11, in Chicago, Illinois.

Narayanan, V.K. & Chen, T. (2009). Standards as the Cornerstone of Technology-based Competition: Accomplishment and Challenges. Paper presented at *2009 Academy of Management Meeting*, August 7-11, in Chicago, Illinois.

Chen, T., Kurokawa, S & Narayanan, V.K. (2008). Innovator's Choice: How Can Technology Leaders Establish de facto Standards in Network Markets? Paper presented at *2008 Annual Meeting of the Academy of Management,* Anaheim, California.

Yang, Y. & Chen, T. (2008). Promoting de facto Standards through Corporate Venture Capital (CVC) Investments: From the Perspective of Agency Theory. Paper presented at *2008 Babson College Entrepreneurship Research Conference* at Chapel Hill, NC.

Chen, T., Kurokawa, S & V.K. Narayanan (2008). Competition for de facto Standards: the Leader Firms' Strategy in Network Markets? Paper selected for discussion at Pre-Conference Workshop of *2008 Atlanta Competitive Advantage Conference*, Emory University, Atlanta, GA.

TEACHING EXPERIENCE

Strategy and Competitive Advantage, Course instructor
Winter, 2009~2010

Introduction to Entrepreneurship, Course instructor with a mentor
Winter 2008~2009; Spring 2008~2009; Summer 2008~2009

Business Policy and Social Responsibility, Course instructor
Spring, 2007~2008

Management Simulation (Capstone Course), Course instructor
Fall, 2006~2007; Spring 2006~2007; Summer 2006~2007; Fall 2008~2009

TEACHING INTERESTS

Entrepreneurship
Management simulation
Technology management
Business policy and strategy

ACADEMIC AWARD AND HONORS

Honorable Mention for Excellent Work in Research (2009) at LeBow College of Business, Drexel University

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PROFESSIONAL AFFILIATION

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