THE CO-EVOLUTION OF TECHNOLOGICAL DESIGNS AND CATEGORIES DURING INDUSTRY EMERGENCE

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Acknowledgements: We would like to thank Steve Kahl, Sarah Kaplan, and Mary Tripsas for their valuable comments on this manuscript.
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ABSTRACT

Technology scholars have long studied the evolution of technological designs during industry emergence. More recently, organizational theorists have begun to explore the role of categories in industry dynamics. Yet, we do not know how designs and categories co-evolve. We build upon these two literatures to propose an integrative process model of industry emergence, and we identify specific mechanisms through which technological designs and categories influence one another. In particular, we focus on how materiality influences the creation and abandonment of categories, and how categories shape both technological recombination and the subsequent technological selection. Our focus on the co-evolution of technological designs and categories and our identification of specific mechanisms add precision and granularity to the existing understanding of industry emergence, creating a much-needed bridge between two bodies of literature that, while addressing similar topics, have evolved largely separately.
INTRODUCTION

Understanding the dynamics of industry emergence and evolution has been a core concern of both scholars of the industry life cycle and organizational theorists. Such dynamics have been associated with firm entry and exit rates (Gort & Klepper, 1982), entry-timing advantages (Lieberman & Montgomery, 1988), and the creation of technological designs that compete with one another until one of them comes to dominate the industry (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). Scholars have highlighted the fact that industries move from a period of ferment, which is characterized by technological divergence and the creation of multiple designs, to a mature stage that sees convergence on one dominant design that is favored by most firms in the industry (Abernathy & Utterback, 1978; Anderson & Tushman, 1990).

While the technological dynamics of industry evolution are relatively well understood, the socio-cognitive aspects of this process have received less attention, even though the value of an integrative approach has not gone unnoticed. In one of the few early integrative attempts, Clark (1985) proposed that technological “design hierarchies” had to be analyzed together with the “hierarchy of consumer choices” (p. 241) to get a full picture of how industries evolve. More recent literature has picked up the challenge and begun to look at the emergence of new market spaces through socio-cognitive lenses, and these scholars have proposed several constructs to capture the socio-cognitive dimension of industry emergence, such as “field frames” (Lounsbury 2001; Lounsbury, Ventresca &
Hirsch, 2003); “technological frames” (Kaplan & Tripsas, 2008; Orlikowski & Gash, 1994); and “schemas” (Bingham & Kahl, 2013).

However, this literature has primarily focused on the role that socio-cognitive constructs that predate the emerging industry play in shaping stakeholders’ perceptions about the new industry. The influence of technologies on socio-cognitive constructs and the co-evolution of the two have received less attention. In particular, the specific mechanisms through which this co-evolution occurs remain unidentified. Indeed, because prior studies have tended to examine *a posteriori* the socio-cognitive lens that eventually becomes dominant, an understanding of how socio-cognitive constructs “emerge and fall out of use” and of “what they come to mean” (Kennedy & Fiss, 2013: 1) is still missing. A more comprehensive understanding of the co-evolution of the socio-cognitive and technological dimensions of emerging industries is important lest researchers face the risk of either technological or social over-determinism (Barley, 1986).

In examining the co-evolution of technologies and socio-cognitive constructs, we focus on categories as the socio-cognitive constructs of interest. We refer to categories as socially constructed partitions that group together objects perceived to be similar (Bowker & Star, 2000). The use of categories over other socio-cognitive constructs used in previous research presents significant advantages, as it allows us to build upon a growing stream of research that has highlighted the formation of categories as one of the fundamental social processes that shape the dynamics of industries (Hsu, 2006; Jones, Maoret, Massa, & Svejenova, 2012; Kennedy, 2008; Kennedy & Fiss, 2013; Navis & Glynn, 2010; Negro,
Several studies have explored the link between categories and firm performance (e.g., Zuckerman, 1999, 2000), and others have begun to explore how categories evolve over time (Kennedy, 2008; Khaire & Wadhwa, 2010; Rosa et al., 1999). Even more importantly, categories not only are abstract socio-cognitive constructs but also constitute basic elements of written and oral communication (Murphy, 2004). Tracking their formation and use facilitates capturing both the enormous variation and the subtle distinctions in meaning that characterize the earliest period of industry evolution (Bingham & Kahl, 2013). Indeed, categorical dynamics are particularly well suited to explaining how a multitude of different stakeholders make sense of a heterogeneous product space (Durand & Paolella, 2012), which allows for theorizing and testing processes of formation and selection (Porac, Thomas, Wilson, Paton, & Kanfer, 1995).

Our paper extends the existing literature in three ways. First, we focus specifically on the co-evolution of the socio-cognitive and technological constructs, and we identify specific mechanisms that shape their interrelationship. Second, we extend theories of industry life cycles by offering a model that explains technological evolution not as stochastic but rather as being strongly influenced by the categories that stakeholders use to make sense of the emerging industry. Third, we extend theories of category evolution during industry emergence by explicitly theorizing on the dynamics through which many different categories are created and some are selected over others. In particular, we suggest
that categories do not emerge in isolation but instead are continually shaped by changes in the objects they are trying to categorize.

In building our theoretical model, we first explore and theorize about technological and categorical dynamics separately before bringing them together into an integrative model. In the following sections, therefore, we detail the evolutionary mechanisms associated with each of the following four processes: technological evolution, categorical evolution, technological evolution’s influence on categorical evolution, and categorical evolution’s influence on technological evolution (see Table 1). While only the latter two processes address the co-evolutionary aspects that are our main focus, we consider it necessary to begin by first reviewing the existing understanding of technological and categorical evolution. The specific mechanisms associated with these evolutionary processes have, indeed, not been explicated fully in the prior literature, and their identification is an important first step toward developing our co-evolutionary model.

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Although the mechanisms we outline below are active throughout the life cycle of an industry, for the sake of clarity we associate each of them with the particular industry period in which they are most prominent. While this is an abstraction, it allows us to highlight the role of the mechanisms more vividly, and it provides additional insights into the temporal dynamics of industry emergence. We develop a set of propositions to explain our theorizing.
Figure 1 provides an overview of our integrative model of the co-evolution of technological designs and categories. Mechanisms already described in existing literature are depicted in solid black type. We use these as stepping stones to identify a number of additional mechanisms and associated propositions that are numbered and depicted using grey type in the figure. Table 2 provides a more complete summary and definitions of the mechanisms behind each process, and we elaborate each of these mechanisms below.

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MECHANISMS OF TECHNOLOGICAL EVOLUTION: UNPACKING THE THEORY OF THE INDUSTRY LIFE CYCLE

Scholars of industry life cycle generally agree that the process of industry emergence often begins with “creative destruction” (Schumpeter, 1934), as novel recombinations initiate an era of ferment that witnesses the entry of firms proposing alternative technological designs (Abernathy & Utterback, 1978; Anderson & Tushman, 1990). The era of ferment is characterized by an increasing divergence in the number of designs as “the rates of product and process changes are high, and there is great product diversity among competitors. During this state, the [innovation] process is fluid, with loose and unsettled relationships” (Utterback & Abernathy, 1975: 641).
The period of fermentation and technological divergence often culminates in the emergence of a dominant design (Abernathy & Utterback, 1978)—“a single architecture that establishes dominance in a product class” (Anderson & Tushman, 1990: 13). The emergence of a dominant design leads to convergence on a few designs and to increased concentration (Klepper, 2002), thereby fundamentally altering the nature of the competition and signaling the onset of the industry’s maturity.

The prior literature typically does not detail the specific mechanisms that underlie technology evolution (see Davis & Marquis, 2005; Hedstrom & Swedberg, 1996). A careful reading, however, suggests three key mechanisms: “technological recombination,” which is primarily responsible for the creation of new technological designs (divergence), while “design competition,” and “path dependence” contribute to the reduction in the number of designs (convergence). Acting together, these mechanisms fuel a complex process through which technological variations emerge and initially increase in numbers before some of them are selected and retained over others that are abandoned (Anderson & Tushman, 1990).

**The Period of Divergence: Technological Recombination and the Creation of New Designs**

While there may be instances of artifacts being created totally anew, in the vast majority of cases new industries emerge from innovations that come about through the creative recombination of technologies (Schumpeter, 1934; Abernathy & Utterback, 1978; Anderson & Tushman, 1990). Technological recombination is the creative synthesis of two or more previously separate technologies that results in the creation of a new technology to address an existing or potential need (Hargadon, 2003). Recombination with older ideas
and technologies occurs even in the case of “breakthrough” or “paradigmatic” technologies that produce entire new industries (Basalla, 1988; Fleming, 2001). Mechanical typewriters, for instance, were created “as a synthesis of many existing elements. Clockwork suggested the idea of the escapement (to move the carriage one letter at a time). A telegraph sender provided parts for the first model for keys and arms. A sewing machine pedal was used for returning the carriage. The piano contributed the concept of the free and swinging arms and hammers for imprinting the letters” (Utterback & Suarez, 1993: 9). In a similar fashion, automobiles combined carriages previously propelled by horses with the internal combustion engine (Rao, 1994), and the biotechnology field was created by applying chemical knowledge to biological phenomena (Plein, 1991).

When the evolutionary path of a new industry is still undefined, and the understanding of customer needs and trends in the emerging market space is poor at best, the possibilities for recombination and experimentation are many. In their attempt to address still-evolving customer needs, different producers enter the emerging market space with different technological designs that correspond to their different understandings of the industry or to their different visions of its future (Kaplan & Tripsas, 2008; Benner & Tripsas, 2012). Essentially, potential recombinations can be as many as (or even more than) the organizations that enter the new market space. By constantly fueling the number of new designs that are introduced to the emergent market, technological recombination can lead to a plethora of technological designs that might differ markedly from one another but that coexist temporarily in the young and still-fuzzy market space.
The Period of Convergence: The Abandonment of Technological Designs

The initial phase of technological design divergence is followed by a phase of design convergence that usually culminates in the emergence of one dominant design (Utterback, 1996). Even though the literature on industry life cycles acknowledges the importance of non-technology factors in the process that leads to the abandonment of some designs in favor of others, the emergence of a dominant design has been largely seen as driven by technological considerations. Abernathy and Utterback (1978), for instance, describe the dominant design as a synthesis of previous designs, a “new product synthesized from individual technological innovations introduced independently in prior products.” More recent research in industry life-cycle theory has elaborated on this idea but still has largely maintained a technological prism to understand dominant designs. For instance, Murmann and Frenken (2006) see the emergence of a dominant design as a “nested hierarchy of design spaces…that play host to technology cycles” (p. 931) and base their understanding of dominant designs on an analysis of the “technological characteristics” (components) and “product attributes” that are associated with different product architectures (p. 941). From this literature, two main mechanisms seem to facilitate the process of convergence toward a dominant design: design competition and path dependence.

Design competition. Selection among alternative designs has long been viewed as the primary mechanism through which dominant designs emerge (Anderson & Tushman, 1990). “Design competition” is the mechanism by which producers and customers make investment choices between alternative designs, choosing those that contain the design elements they prefer (Abernathy & Utterback; 1978). Designs are in flux during this period
because a constant stream of new product designs is created through recombination (Utterback, 1996). Preferences are likewise mutable as producers and consumers toil with the large variety of technological choices and design elements. Gradually, the aggregate decision making by producers and consumers regarding which designs to invest in results in a set of specific design elements gaining favor. As some design elements are retained and others are abandoned, product design in the industry begins to converge on a common set of product features (Murmann & Frenken, 2006). While this process does not preclude the introduction of still-novel designs, it diminishes producers’ incentives and ability to do so because consumers increasingly converge on a set of preferred design elements (Clark, 1985). For instance, in describing the retention of key product-design characteristics in the mechanical typewriter industry such as the single QWERTY keyboard, visible type, the tab feature, the shift-key, and the carriage cylinder, Utterback (1996: 25) noted that “any firm that wanted to offer a keyboard with an innovative arrangement of letters, or that wanted a circular type wheel (like the old Burt design), did so at its peril; it might capture some small niche…but it could abandon any hopes of being a mainstream producer with those sorts of designs.”

Path dependence. In the course of their life cycles, technologies and industries often come to crossroads or “technological guideposts” (Sahal, 1982), where one out of a number of design paths has to be chosen. The alternative technological path that is selected largely determines the course of further development—investments and technological progression along the chosen path by producers and customers eliminate, in practice, the other paths as options because reverting to them becomes technically very difficult or prohibitively costly. Path dependence is thus the mechanism through which prior
technological choices determine subsequent technological possibilities. Path dependence occurs because stakeholders engage primarily in local search (Levinthal, 1997) and because of the “quasi-irreversibility of the investment.” (David, 1985: p. 336) As Clark (1985: 241) points out, “the evolution of a complex product follows a hierarchy of design…there are choices in the development of a design that create precedents and are logically prior to other choices. These precedents create constraints... [that] may be inherent in the physical structure of the product or system, or they may arise because of interdependence between parts.”

The impact of path dependence on technology evolution is more pronounced the further down the design hierarchy a technology is. Although at the early stages of a technology’s evolution markedly different designs might be feasible, after a specific path of technological evolution has been chosen, straying away from it becomes increasingly costly. Remaining designs tend to converge on the chosen path with any technological variation becoming narrower. In the automobile industry, for example, the initial choice of the internal combustion engine over the electric one largely determined the path of the industry’s evolution. Even though the internal combustion engine was initially technologically inferior, continuous investment led to significant improvements in its performance, which were also accompanied by large investments in production capacity and complementary infrastructure (Kirsch, 2000). Recent attempts to return to an electric automobile design have been hindered by the fact that undoing those years of technical decisions is both complex and costly.
MECHANISMS OF CATEGORICAL EVOLUTION: UNPACKING THEORIES OF CATEGORICAL DYNAMICS

Even though the primary focus of the literature in the industry-life-cycle tradition has been on the evolution of technological designs per se, some authors have also highlighted the impact of social dynamics on technological evolution. Clark (1985), for example, notes the influence of consumers’ conceptual frameworks on the introduction and evolution of technological designs. Kaplan and Tripsas (2008) theorize that technological frames (Gash & Orlikowski, 1991; Orlikowski & Gash, 1994) influence firms’ production decisions. Several technology scholars have emphasized the role of institutional actors in the success or failure of different designs (Garud & Kumaraswamy, 1993; Garud & Rappa, 1994; Tushman & Rosenkopf, 1992).

More recently, a growing body of literature on categorization has provided new impetus and powerful theoretical tools for the study of the socio-cognitive factors that influence industry emergence (Jones et al., 2012; Negro, Kocak, & Hsu, 2011; Pontikes, 2012; Rosa et al., 1999). As noted, categories are socially constructed partitions that divide the social space into groupings of objects that are perceived to be similar (Bowker & Star, 2000). Categories “have two basic properties: (1) constituent members, whose inclusion is defined by rules or boundaries pertaining to a common type of product or service, and (2) a concept, label, or identity that reflects the commonalities that link together the members of the category” (Navis & Glynn, 2010: 440).

A category label is a symbol (a word in most cases), which is used to reference a category and, consequently, a larger meaning structure (Peirce, 1958). When people
observe a label, they construct the group of objects that they perceive as being associated with it (Yamauchi & Markman, 1998). A category can thus be seen as the set of objects to which a particular label applies (Bowker & Star, 1999). Categories are important because they determine a set of characteristics that their members can be expected to possess and that distinguish them from or relate them to members of other categories (Vygotsky, 1986).

Extant research has shown the importance of categorization processes in the evolution of new industries (Rosa et al., 1999; Weber, Heinze, & DeSoucey, 2008). However, previous studies in this stream have focused predominantly on the *a posteriori* examination of categories that were successful. They start by identifying one category that became prominent, and they use that category’s history and key developments to explain its success (Etzion & Ferraro, 2010; Jones et al., 2012; Kennedy, 2008; Navis & Glynn, 2010; Weber et al., 2008). This approach, while sound and effective to reconstruct the key events in one category’s rise to legitimacy, essentially neglects categories that never gained prominence. As a result, it does not present a comprehensive picture of the much more diverse and complex process of variation and selection that takes place in emerging industries, where often a multiplicity of categories compete for dominance (Kennedy & Fiss, 2013). Indeed, the dynamics through which many different categories are created and some are selected over others, and especially how categories tend to reflect the material constructs of what they classify, have been left relatively unexplored.

Below, we detail the mechanisms involved in the evolution of categories. We posit that the categorical evolution process bears resemblance to technological design evolution
in that it is also characterized by a period of divergence followed by a period of
convergence. We propose that two main mechanisms contribute to the creation of new
categories: “derivations” and “compounding”. Conversely, two mechanisms contribute to
the reduction in the number of categories: “categorical selection” and “categorical
envelopment”.

**Period of Categorical Divergence: The Creation of New Categories**

Early in the development of industries, stakeholders invent categories in an attempt
to communicate and exchange information about a topic or product that is novel (Pontikes,
2012; Vygotsky, 1986). The creation of categories serves two primary purposes. First,
categories allow different stakeholders (i.e., consumers, producers, and analysts) to make
sense of and discuss elements of the emerging industry and, over time, to come to an
understanding with regard its core traits. Second, novel categories function as markers of
attention to which stakeholders can orient and that can help them to understand that a new
product class is emerging (Granqvist, Grodal, & Woolley, 2013; Ocasio, 2011). However,
when a novel industry is still unfamiliar and its products’ form and use are open to debate,
stakesholders lack consensus regarding the meaning of different categories. Multiple
categories are introduced by different stakeholders that reflect their different perceptions of
the industry (Kaplan & Tripsas, 2008). In the case of producers, categorical introductions
might also correspond to an attempt to promote a certain perception of the industry in order
to gain a competitive advantage (Santos & Eisenhardt, 2009).

In the process of category creation, stakeholders have conflicting incentives
regarding the positioning of a new category as similar to or distinct from existing
categories. Distinctiveness can help set the category apart, highlighting the underlying
novelty of the product or industry. In contrast, invoking similarity enhances information
transfer by tapping into existing understandings and creating links to something already
familiar (Bingham & Kahl, 2013). Associations to other categories position each focal
category in a web of meaning on a categorical map (Peirce, 1958). A low (high) distance
between a pair of categories on this map implies a high (low) degree of conceptual
similarity between them (Kennedy et al., 2012).

As noted earlier, categories are expressed through the use of categorical labels
(Hannan et al., 2007; Moreau et al., 2001; Navis & Glynn, 2010). The choice of words or
phonemes that are used in a categorical label reflects stakeholders’ attempts to build links
to existing categorical schemata by recombining existing elements or, alternatively, to
stress the new category’s novelty by generating a new label. As in the case of technological
designs, categories that are created totally anew tend to be rare. Most new categories
emerge as “hybrids of previously unconnected categories, such as “electronic” book,
“mini” van, or “personal” computer”(Navis & Glynn, 2010: 443). Categories that are
created through recombinations of existing elements have informational advantages over
categories that are created anew without any reference to pre-existing elements because the
act of referencing existing categories suggests meanings and uses for a new technology.
For example, Moreau et al. (2001) show in a lab experiment done before the proliferation
of cameras that capture images electronically (and the subsequent emergence of “digital
camera” as a dominant category to refer to this technology) that using a category label for
the new technology that included “camera” vs. “scanner” influenced how consumers
understood and categorized the new technology. They found that if the technology label
included “camera,” customers would search for the new product in the retailer’s aisle of traditional cameras, whereas if the label included “scanner” they would search for it in the aisle of computer accessories.

While the organizational theory literature on categorization has highlighted the importance of category labels (Hannan et al., 2007; Navis & Glynn, 2010; Pontikes, 2012), the mechanisms through which new category labels are created remain unclear (Kennedy & Fiss, 2013). In contrast, research in linguistics (Bybee, 1985; Giegerich 2004; Farnetani, Torsello, & Cosi, 1988) has suggested two key mechanisms that lead to the creation of new category labels: compounding and derivations.

**Compounding.** A compound is “the simple concatenation of any two or more nouns [or other words] functioning as a third nominal” (Downing, 1977: 810). Compounding allows category proponents to borrow meaning from existing categories in order to invoke familiarity with the novel product that they introduce, or to communicate its defining characteristics (Lieber, 1983). Even the use of phonemes that are familiar can help stakeholders understand a new category and make them more prone to adopt and use it (Berger et al., 2012). Compounds are thus beneficial in managing the tension between familiarity and novelty because they elicit elements of existing categories but also simultaneously represent new and unique recombinations.

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1 Linguists debate the extent to which compounds and noun phrases, where the modifier is a noun, are different (Giegerich 2004; Farnetani, Torsello, & Cosi, 1988)—that is, whether compounding into one word or two words are linguistically distinct. For example “power tool” is created through combining the two nouns “power” and “tool” into a noun phrase, where “power” is the modifier and “tool” is the head, whereas “air” and “plane” are combined into one word “airplane.” The difficulty of distinguishing these two constructions (compounds and noun-noun phrases) made Bloomfield (1933) argue that “ice cream” is a noun phrase to some English speakers and a compound to others. For the sake of our exposition, this differentiation is not important and we will, thus, refer to both noun-noun phrases, and compounds as simply “compounds.”
Examples of new categories emerging through compounding abound. For instance, the category “laptop,” first introduced in 1983 with the launch of Gavilan SC, compounded the words “lap” and “top” to communicate to potential users that the new computer allowed them to sit and work while holding it on their laps, in marked contrast to prior products in that market space that were particularly heavy. Borrowing meaning from existing categories, proponents of a new category can also position a product vis-à-vis others and can often signal its superiority. The category “smartphone,” for example, borrows meaning from the “phone” category to signal that the device can be used to communicate with other people as with earlier mobile devices but that there are “smart” features that signal the device’s sophistication and superiority over earlier devices. By creating associations to pre-existing, familiar categories, and by highlighting similarities to and differences from them, compounds immediately position novel products on the categorical map, thus capturing stakeholders’ attention and enhancing information exchange among them.

**Derivations.** The second key mechanism through which new category labels are created is derivations. In the case of derivations, a new categorical label is created through the novel use or transformation of an existing word, most often by changing an existing word into a different word class, such as going from a verb to a noun (Bybee, 1985). For example, the category “browsers” is derived from the verb “to browse,” and the category “computers” is derived from the verb “to compute.” In contrast to compounds that simply invoke familiarity of established product classes, derivations stress the activity for which the new product is to be used. Specifying the purpose of the new product allows new categories to be more rapidly understood. The extent of meaning transfer, however, is case-specific and time-variant. In the examples above, the purpose of a “browser” or a
“computer” is likely to be intuitively clear to most English speakers, but the exact domain in which they are to be used is less so. In addition, while the categorical label “computer” described well the primary function of early computers, the meaning of the label has evolved significantly since then. Currently, it refers to a machine that performs a rich array of functions, most of which have little to do with computing as most users would understand the term (Bingham & Kahl, 2013). Thus, we offer the following proposition:

*Proposition 1: Most new categories introduced in nascent markets emerge through compounding and derivations.*

**Period of Categorical Convergence: The Abandonment of Categories**

At the early stages of emerging industries, uncertainty and stakeholders’ different perceptions about the industry tend to lead to the introduction of a multitude of novel categories. Such categories can even be espoused and promoted by only a single stakeholder (e.g., a producer that coins a new category for their product offering). Lack of shared meaning and common use imply that the boundaries of such categories tend to be fuzzy and that their positions vis-à-vis other categories are not well delineated, leading to overlap among co-existing categories (Pontikes, 2012). Similar objects might be grouped in different categories and dissimilar objects in the same category, leading to confusion. This stifles understanding and communication among stakeholders, and thus beats the very purpose of the categories’ existence. To resolve such confusion and facilitate better communication, stakeholders gradually gravitate toward the use of fewer categories, the boundaries of which become better defined, whereas those categories that lose traction are gradually abandoned. As in the case of technological designs, the categories that are retained and the ones that falter depends on specific mechanisms that guide this selection.
process. We identify two main mechanisms that lead to categorical convergence: categorical deepening and categorical envelopment.

**Categorical deepening.** When a new category is first introduced, it tends to be shallow in the sense that its meaning is not well defined and its connotations are limited (Peirce, 1958). Over time, however, increasing use of and familiarity with the category, as well as negotiation among stakeholders, expand the category’s semantic connections and better define its meaning (Hannan et al. 2007; Vygotsky, 1986). We use the term “categorical deepening” to describe this mechanism by which categories gradually become more clearly defined.

When a category is introduced, it contains either none or only a few semantic connections to other labels and concepts (Peirce, 1958). Indeed, its initial semantic connections are primarily those implied by the category’s label because they are inherited from the labels through which it has been compounded or derived (Moreau et al., 2001). Over time, however, as a categorical label is used together with, or in juxtaposition to, other labels, connections between the new and existing categories begin to emerge. Connections to existing categories can be invoked either intentionally through the use of analogies—that is, “figures of speech that assert similarities between two domains” (Etzion & Ferraro, 2010: 1094)—or merely through the repeated co-occurrence (in text or speech) of the new category with existing categories (Steyvers & Tenenbaum, 2005). Such connections can invoke similarity or stress differences between the focal category and other categories. In either case, they help to clarify the category’s meaning and to position it “as a node in a network, with [its] properties […] represented as relational links from the node to other concept nodes” (Collins & Loftus, 1975: 408). For instance, in the early 1990s
when the category “e-commerce” was first used by a firm to describe its online activities, its meaning was rather unclear for the vast majority of consumers and other stakeholders, few of whom had Internet access at the time (i.e., the semantic network associated with “e-commerce” was sparse). Indeed, several different activities and types of organizations were associated with the early e-commerce category, such as Electronic Data Interchange (EDI) and Electronic Funds Transfer (EFT), and stakeholders found it difficult to distinguish these from other categories that were emerging in the new market, such as “online retailer” and “dot-com.” As the familiarity and use of the Internet increased through the decade of the 2000s, and as online transactions became common, the meaning of the different categories used in this new space became deeper due to the creation of denser semantic networks associated with each of the categories. “E-commerce” today, for instance, is widely perceived as the sale and purchase of goods and services through the Internet, and as taking two basic forms, “business to consumer” (B2C) or “business to business” (B2B) (Kalakota & Robinson, 2000).

Categorical deepening also implies that categorical boundaries become gradually clearer. A denser meaning structure encourages the emergence of categorical membership rules as stakeholders form concrete expectations about the traits that products belonging to any focal category can be expected to possess. Categories thus become increasingly crisp (Pontikes, 2012) and clearly defined relative to other categories.

The deepening of categorical meaning that occurs as stakeholders gradually develop a more nuanced understanding of each category allows stakeholders to compare categories and choose from among them the ones that are best suited to describe the emerging industry (Rosa et al. 1999). Categories that perform well at this task are retained, while
others that are not picked up are gradually abandoned and disappear. Categorical deepening is thus a key driver of the categorical selection and categorical convergence that takes place in a new industry.

Rosa et al. (1999) demonstrate vividly this dynamics in the “minivan” industry. During the early phases of the industry, a multitude of categories such as “minivan,” “compact van,” and “people mover” were used to reference products in the industry. As stakeholders converged toward the use of the “minivan” category, the competing categories gradually disappeared into the dustbin of history. The authors show that, through use and experience with the products in the emerging market, the conceptual system of minivans came “to be defined as an array of such attributes such as ‘front-wheel drive,’ ‘low step-in height,’ and ‘seven-passenger,’” which gradually formed a “stable attribute nomenclature” (p. 67) that helped sharpen the boundaries of the minivan category.

Categorical envelopment. The second mechanism of categorical convergence that we identify is that of categorical envelopment. In contrast to categorical deepening, which leads one category to be selected over competing alternatives, categorical envelopment involves the broadening of one category’s meaning to the point that it fully encompasses the meaning of another. In this case, the narrower category’s defining characteristics become taken-for-granted elements of the larger category, causing the narrower category to cease to exist independently (Colyvas & Powell, 2006).

At the early stages of the “smartphone” industry, for example, categories such as “camera phone” and “PDA phone” had gained traction describing different segments of the industry and products with different capabilities. Eventually, however, both categories were enveloped by an expanding smartphone category. As technology and consumer preferences
continued to evolve, the characteristics that defined the categorical meaning of camera phones (i.e., that they could be used to take and store photos) and PDA phones (i.e., digital calendars to organize daily events) became central to the meaning of all devices belonging to the “smartphone” category, rendering the categories of “camera phones” and “PDA phones” redundant.

Categorical deepening and categorical envelopment are both indicative of how categories are largely defined in terms of similarity to or difference from other categories (Peirce, 1958; Weber et al., 2008). If two or more categories overlap significantly on the dimensions that stakeholders deem important, or if one or more categories are subsets of a larger category, envelopment is likely to occur and lead to the abandonment of the narrower categories. In contrast, if two categories are very distant, the markedly different perceptions of the industry that they incarnate might not be able to coexist within the same industry. In these cases, stakeholders’ convergence toward one dominant perception leads to categorical selection and the abandonment of categories that stakeholders do not favor. In this selection process, categories that are created through compounding and derivations are likely to have a competitive advantage over categories that are created de novo because they balance the trade-off between distinction and understanding (Bingham & Kahl, 2013) by inherently invoking both familiarity and novelty. We therefore propose the following:

*Proposition 2a:* Categorical deepening and categorical envelopment are the basic mechanisms associated with the abandonment of categories.

*Proposition 2b:* Categories created through derivations and compounding are more likely to survive categorical selection than categories that are newly created.
THE INFLUENCE OF TECHNOLOGICAL EVOLUTION ON CATEGORICAL EVOLUTION

In the preceding sections, we detailed the mechanisms of categorical and technological evolution, examining them independently of one another. However, categories and technological designs do not develop in a vacuum but rather bear direct influence on one another’s evolution. In the following sections we detail the mechanisms through which technological evolution shapes categorical evolution and vice versa. We begin with the influence of technological designs on categories, and propose that it occurs through two main mechanisms: “technological echoing” and “feature-based clustering.”

**Technological echoing.** In the section on categorical evolution, we described how new category labels are created through derivations and compounding, but we remained rather unspecific with regard to the mechanisms that drive the choice of the original labels that are used in compounds or derivations. This choice, however, is not random because derivations and compounds are often formed to reflect the materiality of what they are categorizing, which changes with technological developments. We define technological echoing as the mechanism through which technological designs influence the creation and evolution of categorical labels.

In an emerging industry where technologies, categories, products, and even user needs are in flux and poorly understood, compounds and derivations often reflect the actual or aspired technical characteristics of the product. Because understanding of the new product is poor, referencing its defining technological characteristics helps stakeholders to better grasp its function and to position it with respect to preexisting products. In the early stages of what is now called the automobile industry, for example, early compounds such as “auto-mobile” and “horseless carriage” (see Rao, 1994) directly referenced the new
vehicle’s main technological characteristic—the fact that it was self-propelled. This set the new product clearly apart from previous products and technologies that all relied on horses as their driving power. Similarly, categories such as “electric car” or “power tools” make direct reference to the corresponding products’ main technological characteristics.

It follows that the more heterogeneous the technological designs introduced in the new industry are, the more possibilities there are for echoing from those designs in order to create new categorical labels. Design heterogeneity can spring from differences in the underlying materiality of the technologies (such as the type of engine in the auto example above), or from differences in specific design characteristics even for products with similar underlying technologies (such as in a “sedan” vs. a “coupe”). Thus, we propose an inherent relationship between technological recombinations and the new categories created in early industries:

*Proposition 3a (technological echoing): Most of the words or word stems recombined or altered in compounding and derivations to form category labels reflect core traits of the underlying technology.*

*Proposition 3b: The greater the heterogeneity of technological designs, the higher will be the number of categories created through compounds and derivations.*

**Feature-based clustering.** We define feature-based clustering as the mechanism through which the stakeholders’ perceptions of commonality between specific technological features developed through experience and use lead them to group together products that they deem similar. By facilitating the grouping and comparison of different products, feature-based clustering potentiates the mechanisms of categorical deepening and categorical envelopment, which in turn drive categorical convergence.
As noted earlier, the existence of ill-defined and overlapping categories in early industries creates much confusion among stakeholders. Information that allows stakeholders to better define and compare the competing categories helps them in their process of selecting some categories over others and making sense of the evolving market space. Material elements of design- or technology-specific characteristics provide information that aids stakeholders’ sense-making and decision processes. As stakeholders gain experience with the new industry, their ability to judge the similarities or differences among products and technological designs increases. Products that are judged to be similar in terms of key technological features are considered to be “close” and are often clustered together in one category. In contrast, products deemed to differ on these same features will be categorized differently (Murphy, 2004; Hannan et al., 2007). Technological clustering, therefore, sharpens categorical boundaries and allows for meaningful groupings, which in turn can help to potentiate the mechanisms that drive categorical convergence—i.e., categorical deepening and envelopment. Sharper category boundaries reduce confusion and facilitate the selection between categories by the different stakeholders. Similarly, sensible groupings of different designs based on specific technological features bring the original categories associated with those different designs closer together in a categorical map (Peirce, 1958), which facilitates the process of categorical envelopment.

For example, during the early development of technologies at the nano-scale in the 1980s, these technologies initially carried different labels across different disciplines. Materials scientists referred to such technologies as “single-layer depositionings” or “advanced materials,” physicists referred to them as “mezzo-science,” chemists used the term “molecular control,” government officials called the discipline “nano-science,” and
some service providers referred to it as “nanotechnology” (Granqvist, Grodal, & Woolley, 2013). Over time, however, stakeholders from different disciplines began to realize that the technologies labeled differently by different stakeholders actually had a high degree of similarity in terms of technological properties in that they were all on the nano-scale. As stakeholders started clustering together technologies at the nano-scale, they also began using a common label, referring to them collectively as “nanotechnology.” The label nanotechnology thus came to envelop the other existing labels, which all but disappeared—a process that was largely dependent upon stakeholders creating clusters of similar technologies. Therefore, we propose that feature-based clustering affects how categories are selected and which categories are enveloped:

Proposition 4 (feature-based clustering): The greater the stakeholders’ perceptions of commonality between technological features in different designs, the larger will be the number of categories that are abandoned through the mechanisms of categorical deepening and envelopment.

THE INFLUENCE OF CATEGORICAL EVOLUTION ON TECHNOLOGICAL EVOLUTION

Theories of technological design evolution are often criticized for their implicit assumptions about the importance of stochastic technological shocks (Garud & Kumaraswamy, 2010). In reality, however, the process of technological design evolution has strong socio-cognitive underpinnings (Shane, 2000; Abrahamson & Rosenkopf, 1993; Garud et al., 2002). Categories in particular, as embodiments of different perceptions of an underlying technology and its envisioned use, can play a significant role by influencing design decisions and thus a technology’s evolutionary path. We identify two mechanisms
through which categorical evolution shapes the process of technological evolution:
“categorical echoing,” and “membership directing.”

**Categorical echoing.** The extensive literature on the role of recombinations in the evolution of technological designs has focused primarily on the technological aspects of the process (Abernathy & Utterback, 1978; Utterback & Suarez, 1993). Technological recombinaton, however, does not occur in a vacuum. While technological capabilities determine which recombinations are feasible, the identification of the ones that will actually be pursued depends upon perceptions about their relevance and desirability (Clark, 1985). Such perceptions, in turn, are socially constructed and expressed in categories. We define categorical echoing as the mechanism through which categories influence technological recombinaton.

Categories constitute the lenses through which an evolving market space is understood (Moreau et al., 2001; Rosa et al., 1999). Invoking a larger meaning structure, they can have a marked influence on the technological features that are deemed desirable, and thus on the specific technological evolution path that will be pursued (Garud & Rappa, 1994). The creation of novel categories by the different stakeholders can spur recombinations that producers would otherwise not have considered. This happens because the specific alternatives that producers pursue depend not only on their technical feasibility but also on how prominently they figure in the producers’ cognitive repertoire (Clemens & Cook, 1999). In addition, even when a certain recombinaton is currently not feasible, categories can direct technological search in its direction and influence which technological features will eventually be available. For instance, the “camera phone” category used by several producers to position their devices in the early phase of the smartphone industry
may have directed companies to work on including additional features associated with cameras in their new devices, including zooming capabilities and flash. Similarly, the “gaming-device” category adopted by other early producers in this space to position their products may have led to the introduction of larger screens and research on improved graphics.

Thus, the multitude of compounds and derivations that stakeholders create in early industries not only function to attract the attention of stakeholders and transfer information about the underlying product but also to ultimately shape the path of technological creation by stimulating new technological recombinations. Therefore, we propose the following:

Proposition 5 (categorical echoing): The specific paths and extent of design activity by producers in an early industry will be influenced by the type and number of categorical compounds and derivations created by stakeholders.

Membership directing. Categories also guide technological evolution by setting boundaries around the specific design features that are accepted as belonging to a product category. As noted earlier, the meaning of the categories deepens as the industry evolves, sharpening categorical boundaries. These changes, in turn, begin to establish rules of categorical membership that increasingly dictate the characteristics of products or technologies that belong to a focal category. We define membership directing as the mechanism through which categories exert influence over the design process by implying which features a product design needs to possess (i.e. rules of inclusion) and which traits it cannot possess (i.e. rules of exclusion) in order to claim membership in a particular category (Vygotsky, 1987; Yamauchi & Markman, 1998).
The rules of membership imposed by categories can be quite detailed (Hannan et al., 2007). For example, Meyer (1995: 46) shows that the defining characteristic of the now-obsolete “pen computing” category was “the use of a pen or pencil as the primary means of interaction between a user and a machine.” A producer whose product did not use a pen for writing directly onto a computer screen, yet claimed membership in the “pen computing” category, would see its claims questioned.

Conversely, even if a product possesses all of the traits dictated by a category, the introduction of features that are seen as incompatible with the category might bring the product’s membership claim into question. In the motorcycle industry, for example, stakeholders’ categorical understandings emphasize that motorbikes are not supposed to have more than two wheels. Having three or four wheels creates confusion, as it blurs the boundaries between the “motorcycle” and the “automobile” categories and violates the implications associated with motorcycles such as “freedom” and “risk-taking.” In a similar vein, Seidel and O’Mahony (forthcoming: 23) describe how the idea of adding a calculator to the capabilities of an “eBook” was abandoned because having a calculator did not fit well with the dominant perception associated with the “book” category. In contrast, however, having an address book was deemed an acceptable characteristic of products claiming membership in the category:

Someone had a long discussion about why we would need a calculator in it [the eBook]. At the end, [the project manager] would go, “But it's a book!” The manager’s implication was that books did not have calculators and, to be consistent with that metaphor, neither should the eBook. In another instance, the question of whether to allow a list of contacts on the eBook was addressed differently. The executive manager explained that “someone can have a little black book of names [which] is a book also. So it fits the paradigm.
Membership directing reinforces the effects of technological competition and path
dependence. As categories and stakeholders’ corresponding understandings of the industry
solidify, products or technologies that stray too far from them are likely to be penalized
(Zuckerman, 1999). Variations or advancements of a technology are thus constrained not
only by the limits set by technological path dependence, but also by the expectations set by
the rules of membership to a category. Membership directing limits product variation based
on technological features, which intensifies the process of technological convergence.
Therefore, we propose the following:

Proposition 6 (membership directing): The sharper the categorical boundaries
and rules of membership, the more technological designs that will be
abandoned through the mechanisms of design competition and path
dependence.

A PROCESS MODEL OF THE CO-EVOLUTION OF TECHNOLOGICAL
DESIGNS AND CATEGORIES

We set out in this paper to integrate industry life cycle theory with organizational
theories of categorization in order to detail their co-evolution and reach a more nuanced
understanding of industry emergence. Our theory and the proposed mechanisms are
summarized in the temporal process model depicted in Fig. 1.

The mechanisms through which categorical and technological evolution occur unfold
horizontally on each side of the figure. Both technological and categorical evolution first
undergo a period of divergence: the number of technological designs and categories
increase during this period, fueled respectively by technological recombinations and
compounding and derivations. The initial period of divergence is generally followed by a period of convergence: the number of categories and technological designs in use decreases significantly, fueled respectively by design competition and path dependence, and by categorical deepening and envelopment. For simplicity, we have depicted in Fig. 1 the transition from the phase of divergence to the phase of convergence as roughly co-occurring for technological designs and categories. This is not necessarily always the case in reality, but given that technological designs and categories co-evolve, the two points of transition are unlikely to be very far apart.

Indeed, as the figure also makes apparent, categories and designs do not evolve independently but instead directly influence one another. These co-evolutionary processes are present during both the early period of divergence and the later period of convergence. During the period of divergence, technological recombinations are influenced by categorical echoing, as categorical structures directly affect which technological designs that producers choose to explore and develop. At the same time, newly created categories are influenced by technological echoing, as derivations and compounds often directly reflect the technological designs that they reference.

During the phase of convergence, categories influence the further evolution of technological designs through the mechanism of membership directing. Those technological designs that better fit the emerging categorical structure are better understood and enjoy an advantage over competing technologies. Moreover, as categories gradually solidify, membership directing further reinforces technological path dependence by
creating specific rules regarding which technological extensions fit with the existing
categorical structures and which fall outside it. Likewise, technological designs influence
the evolution of categories during convergence through the mechanism of feature-based
clustering. As the differences and similarities between technological designs begin to be
better understood, and as the number of designs remaining in the market decreases
significantly, stakeholders can more easily make sense of and compare existing categories
by contrasting the technological characteristics of the products they contain. Thus,
technology evolution during convergence strengthens the mechanisms of categorical
deepening and envelopment.

In most industries, the outcome of the co-evolution between technological designs
and categories eventually leads to the establishment of one dominant technological design
(Abernathy & Utterback, 1978) and one dominant category (Suarez et al., forthcoming; see
also Kaplan & Tripsas, 2008, and their related concept of a collective frame). While a
dominant design is the product architecture that achieves dominance in a product class
(Anderson & Tushman, 1990), a dominant category is the category that most stakeholders
use when referring to the emerging industry.

**DISCUSSION**

Our paper expands the literature on industry life cycles and categories in several
ways. We highlight the importance of categories during industry emergence, particularly by
proposing an integrated model of industry evolution that takes into account the co-
evolution of technological designs and categories. While some scholars of the industry life
cycle have pointed to the role of socio-cognitive factors (see Clark, 1985; Kaplan & Tripsas, 2008; Sahal, 1982), our model offers a higher degree of theoretical granularity that facilitates a more precise description of the evolutionary process.

We leverage the rich literature on categorical dynamics (Kennedy, 2008; Navis & Glynn, 2010; Rosa et al., 1999), to describe in detail the mechanisms that drive the evolution of designs and categories, as well as their co-evolution. By developing testable propositions and specific mechanisms, we extend our understanding of several of the mechanisms that have been central to the industry life-cycle literature. In particular, we show that the basic dynamics of the industry life cycle such as technological recombination, competition, and path dependence are partly shaped by categorical dynamics. For example, the existing literature on industry life cycles describes the emergence of a new industry as stimulated by recombinations “whose direction and objectives are defined by a specific set of technical opportunities and constraints” (Clark, 1985: 237). While technological constraints determine the set of feasible recombinations, the number of recombinations that are actually tried is generally considered to be stochastic. In contrast, we theorize that recombinations do not happen in a vacuum but instead are facilitated by existing categorical understandings. Such understandings not only constrain the technological recombinations that are considered desirable but also can suggest novel recombinations and paths toward further technological development.

Likewise, not only does design competition pitch features against features in the struggle for dominance but also stakeholders’ selections are partly shaped by the categorical position of each design in the market.
In addition, we add to the literature on industry life cycles by introducing mechanisms by which industry boundaries might be formed. Although a crucial aspect of industry evolution is the identification of industry boundaries (Santos & Eisenhardt, 2009), the existing theory of the industry life cycle has surprisingly not paid much attention to defining what an “industry” is. For instance, Anderson and Tushman (1990: 606) use “standard industry boundaries” in their study, as defined by the 4-digit Standard Industrial Classification (SIC) codes, which are defined by “similarities in the production processes or consumer demand” (Department of Revenue Website, October 2012). The idea of similarity used in SIC codes comes most likely from economics, particularly the insight that an industry consists of a group of products that are good substitutes for one another, as evidenced by high cross-elasticities of demand. However, scholars in both economics and industry life-cycle research have rarely focused on how stakeholders come to perceive products as similar, which is a key antecedent of cross-elasticity and thus represents the formation and delineation of industries. Tellingly, Tirole (1988: 13), in one of the most widely used textbooks in industrial economics, states upfront that:

…for the purpose of the present book, this empirical difficulty of defining a market will be ignored. It will be assumed that the market is well defined, and that it involves either a homogeneous good or a group of differentiated products that are fairly good substitutes.

Our model suggests that by studying the evolution of categories in emergent spaces we can shed light on the important and unresolved issue of industry boundaries. Products that are placed within the same category become perceived as more similar, which strengthens competition and substitutability among them. Categorical selection and envelopment help to define the set of products that are seen as similar. As some categories are chosen over others, the meaning of and membership in the remaining categories
becomes clearer and, as a result, the boundaries of what we begin to call an industry become increasingly sharp. The emergence of a dominant category (Suarez et al., forthcoming) espoused by most stakeholders is the culmination of this boundary-definition process and denotes a marked reduction in the cognitive ambiguity that characterized the earlier stages of the industry.

We contribute to existing theories of categorization by theorizing the dynamics of categorical evolution and the variation-selection process that ensues, thereby beginning to address the call by Kennedy and Fiss (2013) to study the process through which categories emerge and fall out of use. Prior studies have either focused on the role of categories in industry dynamics by studying their cross-sectional effects (Zuckerman, 1999, 2000; Hsu, 2006) or focused primarily on the processes through which a single category becomes legitimized (Weber et al., 2008; Navis & Glynn, 2010; Jones et al., 2012). An emphasis on the success of a single category, however, overlooks the fact that the creation, evolution, and dominance of one particular category are intrinsically related to the creation, evolution, and survival of competing categories. Our work suggests that a more complete understanding of the categorical dynamics that take place in an industry life cycle requires that we study both those categories that persist and those that fail.

We also contribute to the categorization literature by highlighting the importance of materiality. While general theories of categorization have suggested that features are important to categorization tasks (Yamauchi & Markman, 1998; Vygotsky, 1987), this link to materiality has tended to be static. Our work adds a dynamic perspective to the role of materiality by theorizing about how stakeholders’ attention to design features can be used
to provide a deeper understanding of the categorical dynamics throughout the industry life cycle.

Furthermore, our approach allows us to delve deeper into the origins of categories to examine both how categories assume their labels and how stakeholders determine which product features are deemed salient for the process of categorization. More attention has been paid lately to the role of category labels in industry dynamics (Hsu & Hannan, 2005; Navis & Glynn, 2010; Pontikes, 2012). Most of this research has focused on the performance implications of claiming multiple labels simultaneously (Hsu, 2006; Hsu, Hannan, & Kocak, 2009), whereas other studies have examined the impact of ambiguous labels (Pontikes, 2012; Ruef & Patterson, 2009). We extend this research by theorizing about the initial process of labeling a category. We suggest that this process is particularly important, especially insofar as the way in which novel categories linguistically invoke associations to preexisting categories bears direct influence on stakeholders’ perceptions and adoption.

At the heart of our theorizing is the idea that the creation of new categories and technologies is not as stochastic as prior research may have led us to believe. Categories and technologies do not emerge in a vacuum but rather are the result of the continuous interplay of socio-cognitive and technological dynamics. Totally novel categories and technologies are indeed very rare. The theory we have developed in this article furthers our understanding of these important relationships and opens up several avenues for future empirical research. Some of these involve research questions that emanate directly from our propositions and theorizing, and other possible research questions can be derived from the integrative model of Fig. 1 and its implications. For instance, what is it that determines
whether categorical or technological convergence occurs first? The answers to this and other questions have the potential to substantially increase our understanding of industry emergence.

**Boundary Conditions**

We have detailed the processes of technological and categorical evolution that culminate in the emergence of a dominant design and a dominant category. However, there are boundary conditions to these processes.

We noted earlier that categories often expand to envelop narrower ones and include increasingly diverse elements (Pontikes, 2010). Stakeholders’ increasing degree of sophistication and technologies’ further evolution might render such broader categories unfit to accurately describe the dimensions that stakeholders consider to be important. In such cases, categories might partition into several subcategories that better capture differences between continuously evolving products, thus forming a hierarchy of categories (Lakoff, 1987). For example, categories like “minivan,” “SUV,” and “convertible,” are all subcategories of the “automobile” category that emerged to capture specific characteristics on which members of the automobile category differed and that were deemed important by stakeholders.

Subcategorization is likely to occur in other situations as well. First, as Suarez et al. (forthcoming) note, sometimes the convergence on a dominant category happens too quickly. In such cases, the membership rules used to determine inclusion in or exclusion from the category remain unclear, and the dominant category might thus become too broad to be
meaningful. Narrower and more meaningful sub-categories might therefore subsequently emerge to replace the dominant category. For example, the artificial intelligence (AI) category had gained significant traction early on, but later it broke up into subcategories such as “neural networks,” “intelligent control,” and “natural language processing” (Crevier, 1994). Second, sometimes firms find it advantageous to try to re-position their products in categories different from the dominant category. This situation typically occurs when firms are underperforming or have difficulties adapting to the intense, price-based competition of mature, well-defined industries (Zuckerman, 2000). Third, a dominant category might be rendered obsolete by further technological development. As technology evolves and new recombinations become feasible, the dominant category might lose its ability to accurately capture the products in the industry. These three scenarios all generate interesting research questions for the future as we try to learn more about which conditions might lead certain categorical and technological processes to prevail over others.

In conclusion, the theory we have built in this paper points to interesting and fruitful new research opportunities. While progress has been made separately in the understanding of technological and categorical evolution during industry emergence, more research is clearly needed to understand how these two related processes interact. We believe our paper constitutes an important early step in that direction.
REFERENCES


Murmann, J.P. & Frenken, K. 2006. Toward a systematic framework for research on


TABLE 1 Mechanisms Shaping the Co-evolution of Technological Designs and Categories

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<td>Technological recombination</td>
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<td>Technological → Technological</td>
<td>Technological recombinations</td>
<td>Technological recombination is the creative synthesis of two or more previously separate technologies that results in the creation of a new technology to address an existing or potential need.</td>
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<td>Design competition</td>
<td>Design competition is the mechanism by which producers and customers make investment choices between a set of designs choosing products that contain the design elements they prefer.</td>
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<td></td>
<td>Path dependence</td>
<td>Path dependence is the mechanism through which prior technological choices determine subsequent technological possibilities.</td>
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<td>Categorical → Categorical</td>
<td>Compounding</td>
<td>A compound is the simple concatenation of any two or more nouns [or other words] functioning as a third nominal.</td>
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<td></td>
<td>Derivations</td>
<td>Derivations are the creation of new labels based on existing labels or words. Often this is the mechanism through which words are changed into a new syntactical category.</td>
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<td>Categorical deepening</td>
<td>Categorical deepening is the mechanism through which over time a category’s semantic connections become more elaborate.</td>
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<td>Categorical envelopment</td>
<td>Categorical envelopment involves the broadening of one category’s meaning to the point that it fully encompasses the meaning of another category.</td>
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<td>Technological → Categorical</td>
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FIGURE 1 Technological and Categorical Evolution during Industry Emergence

**Technological Evolution**

**Categorical Evolution**

Period of technological and categorical divergence

Period of technological and categorical convergence