Customer preference discontinuities:  
a trigger for radical technological change

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Abstract

The technology life cycle literature provides strong theoretical foundations that explain how an era of technological ferment culminates in a dominant design, as well as how technology progresses during the resulting era of incremental change. But the processes by which subsequent technological discontinuities occur, particularly their timing, remains relatively unexplored. What factors cause an industry to move from maturity back to a period of turbulence? This paper develops a model of technological evolution that incorporates both technological trajectories and a new concept: preference trajectories, which are cycles of incremental and discontinuous change in preferences. Preference discontinuities turn out to play an important role in triggering technological transitions in an industry. The model is illustrated using an in-depth historical study of 100 years in the typesetter industry, which underwent three major technological transitions, each of which was driven by preference discontinuities.
1. Introduction

Numerous scholars have proposed models of technological evolution in which long eras of incremental innovation based upon a particular set of technologies are punctuated by periods of radical discontinuous change (1975; Nelson and Winter 1977; Dosi 1982; Sahal 1985; Tushman and Anderson 1986). During eras of incremental change, firms engage in local search resulting in exploitative, competence-enhancing improvements that build on a core of scientific knowledge (Nelson and Winter 1982; Tushman and Anderson 1986; March 1991). Discontinuous shifts occur when products that draw upon fundamentally different science invade the industry, eventually displacing products based on the prior technology.

Much of this prior work has focused on supply-side explanations for these technological transitions, arguing that new technology enters an industry either when the old technology begins to reach its natural limits (Sahal 1985; Foster 1986; Fleming 2001) or when exogenous new science emerges (Dosi 1982). While supply-side conditions can be important, recent work has also begun to highlight the importance of demand-side factors. Christensen, Adner and their co-authors (Christensen and Rosenbloom 1995; Christensen and Bower 1996; Christensen 1997; Adner and Levinthal 2001; Adner 2002) have focused on how the interplay between technological progress and the heterogeneous preferences of different customer segments can result in the disruption of an industry by new technology. The explicit assumption in all of this work, however, is that preferences are relatively static.

In this paper I explore the implications of major preference shifts – what I call preference discontinuities – for technological change. I introduce the concept of preference trajectories: periods of incremental preference evolution punctuated by discontinuous changes in preferences,
and argue that preference discontinuities can also be the catalyst for technological transitions. A radical change in preferences can alter the relative attractiveness of different technologies and thus trigger the introduction of new technology in an industry.

I identify a range of factors that might drive preference discontinuities. First, shifts in the socio-political environment including regulatory change, new legislation, political turmoil, or other exogenous shocks, can alter user preferences. Second, when a product is part of a broader modular system, interdependencies and shifting bottlenecks can impose new functionality and/or performance requirements. Third, the evolution of customers over time, including their increased size and complexity or expanded applications of the technology after prolonged experience, can fundamentally alter needs. Finally, proactive moves on the part of producer firms to shape preferences through media and industry institutions can shift customer willingness to pay for given attributes.

I combine the concept of preference trajectories with prior work on technological trajectories to develop a conceptual model that deepens our understanding of the technology life cycle -- specifically the timing of technological transitions in an industry. I illustrate this model with a detailed study of the evolution of customer preferences and technology in the typesetter industry over a 100-year period. Over this time period, the industry experienced three major technological transitions, and these data suggest that the timing of these technological discontinuities was driven by preference discontinuities.

2. Evolutionary models of technological change

A well-established literature describes the evolutionary nature of technological change in an industry (Utterback and Abernathy 1975; Abernathy 1978; Dosi 1982; Nelson and Winter
These models, with subtle distinctions, describe an industry-level process of variation, selection and retention. High levels of technological turbulence occur early in the emergence of an industry as competing technologies vie for acceptance. During this initial period of ferment both technical and market uncertainty are high. Experimentation occurs both within and across firms as that uncertainty becomes resolved (Thomke 2003; Murray and Tripsas 2004).

Eventually the industry converges on a particular dominant design: a set of technologies and associated problem-solving heuristics and search routines. This convergence process is influenced by a range of economic, social, cognitive, political, and institutional forces (Van de Ven and Garud 1993; Rosenkopf and Tushman 1994; Utterback 1994; Rosenkopf and Tushman 1998; Kaplan and Tripsas 2004). Increasing returns arising from economies of scale and/or network externalities can tip the industry toward a particular technology (Arthur 1989; Cusumano, Mylonadis et al. 1992; David 1992). Socio-cognitive forces also drive convergence as actors develop a common set of beliefs about the industry (Garud and Rappa 1994; Fligstein 1996; Rosa, Porac et al. 1999). Once a dominant design is established, innovation is incremental, following a “natural trajectory” (Nelson & Winter 1977) or “innovation avenue” (Sahal, 1985) that builds upon that dominant technology. User preferences during this period are assumed to have stabilized and firms focus on increasing the efficiency of production processes (Utterback and Abernathy 1975). Long periods of incremental innovation are punctuated by technological discontinuities, which spark a new era of ferment as multiple technological variants compete for dominance (see Figure 1).

------- Insert Figure 1 about here -------
The empirical validity of the technology life cycle model has been well established. While early work focused on the automobile industry (Abernathy 1978), historians of technology have documented cycles of radical and incremental technological change in multiple industries including photography (Jenkins 1975), jet engines (Constant II 1980), watches (Landes 1983), machine tools (Noble 1984), and synthetic dyes (Murmann 2003). Technology management scholars have also explored the organizational and competitive implications of these cycles in the medical imaging (Mitchell 1989), cement, minicomputer (Anderson and Tushman 1990), photolithography (Henderson and Clark 1990), robotics (Katila and Ahuja 2002), paint and photography (Benner and Tushman 2002), pharmaceutical (Rothaermel 2001), and disk drive (Christensen and Bower 1996; Chesbrough 1999; King and Tucci 2002) industries. Finally, economists have mapped technology cycles and patterns of firm entry and exit over time (Klepper and Grady 1990; Agarwal and Gort 1996; Klepper 1996; Shane 2001).

While the robustness of the empirically observed life cycle patterns is clear, our understanding of the factors driving the progression between stages is incomplete. In particular, the timing of discontinuities is not well understood. Why, after years of incremental innovation within the constraints of a dominant design, does a technological discontinuity occur when it does? What triggers a technological transition?

2.1 The role of technological limits

A number of scholars have argued that new technology invades an industry when the old technology is approaching its performance limits. Sahal (1985) proposes that a particular

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1 Dominant design (Abernathy & Utterback (1978); Tushman & Anderson (1986), technological paradigm (Dosi, 1982) and technological guidepost (Sahal, 1985) all represent similar constructs. For purposes of exposition, we
technology will develop along an “innovation avenue” until the natural limits of scale and complexity severely restrict the potential for additional improvements, at which point a new technology takes over. Dosi (1982) also notes that the path of technological change “shows a momentum of its own” as problem-solving activities focus on the “normal” problems of improving performance through elaborations of the dominant design. Eventually there are diminishing returns to ongoing elaboration. Foster (1986) identifies the limits of an existing technology by tracing its S-curve, the performance of a technology relative to the amount of engineering effort expended on improving it. When the old technology is reaching the point of diminishing returns on the investment in engineering effort, new technology at the beginning of its own S-curve will replace the old. Finally, Fleming (2001) argues that firms reach “recombinant exhaustion” as they engage in local search related to a particular set of technologies, which drives them to explore more distantly for radical new technologies.

Other empirical work, however, has cast doubt upon technological limits as a way to predict the timing of technological change. Christensen (1992) tracks the evolution of component technology in the disk drive industry and finds that, while the improvement in individual component technologies followed an S-curve pattern, the flattening out of the S-curve differed by firm. This result suggests that limits to a technology are as much a result of firm-specific capabilities and firm expectations about the technology as they are a result of natural technological limits. Similarly, Henderson (1993) demonstrates that optical photolithography far outlived its expected life as a result of what turned out to be erroneous assumptions about the technology’s physical limits. So while technological limits may sometimes be important drivers of transitions, they do not tell a complete story.

utilize the terminology of Abernathy & Utterback (1978); Tushman & Anderson (1986) except where noted.
2.2 The role of demand

The historical debate in the economics literature between technology-push and demand-pull has highlighted the importance of demand in explaining the rate and direction of technological change (Schmookler 1966; Mowery and Rosenberg 1979; Thirtle and Ruttan 1987). Schmookler (1966) demonstrates that the allocation of resources to inventive activity across a range of industries is driven by the level of demand, but he does not address the specific direction of technological advances within an industry. The literature on induced innovation does address the micro-level inventive activity surrounding a specific technology, but the focus is on cost reducing innovation, in particular reactions to shifts in factor prices (see Thurtle & Ruttan, 1987 for a summary and critique of this literature).

Recent work in the field of management has also explored the interplay between the structure of demand and the technology life cycle, highlighting the significance of emerging customer segments with different preferences. Christensen’s well-known study of the disk drive industry (Christensen and Rosenbloom 1995; Christensen and Bower 1996; Christensen 1997) finds that new technology in the form of smaller drives was first applied to new customer segments that cared about such attributes as size and weight. Even though the smaller drives underperformed the old technology on the traditional attribute of total disk density and were therefore not attractive to existing customers, the drives better met the preferences of new customers. They were adopted by the emerging segment and, with improvements on historical dimensions of merit, eventually invaded the mainstream. Using computer simulation Adner (2002) further develops this finding, showing that the degree of overlap in preferences between different customer segments can explain when technological progress might result in such
disruptions. Ander & Levinthal (2001) also model the effect of demand heterogeneity and show that it can explain the level of investment in product vs. process innovations over the technology life cycle. While an important contribution to our understanding of the interplay between technology and demand, this research does not address the role of changing consumer preferences. It assumes that the preferences of each customer segment are relatively static.

The potential importance of changing preferences is alluded to by Clark (1985) as well as Abernathy and Clark (1985) in work that explicitly considers the interaction between technological and market shifts. Clark (1985) characterizes industry evolution using two parallel hierarchies: a design hierarchy and hierarchy of customer concept formation. Relating these hierarchies to the technology life cycle, he notes that as technological choices are made, there is movement down the design hierarchy and ultimately convergence upon a particular dominant design. At the same time, there is an interdependent movement down the customer conceptual hierarchy as learning occurs and needs become more fixed. Movements back up the design hierarchy can result from both new technology and shifts on the customer side. Clark (1985, p.246) notes “changes in customer concepts may ‘re-open’ certain items on the technical agenda.” Similarly, in examining the causes of industry “de-maturity,” Abernathy and Clark (1985, p.73) note that in addition to the possibility that new technology opens new design options, “new customer demands may impose requirements that can best be met with new design approaches.” In developing my model, I extend the seed planted by this work and explicitly examine both the nature of changes in preferences as well as the factors that might cause these changes.
3. An integrated model of technological transitions: the role of preference discontinuities

Figure 2 illustrates the core components of the model. The basic premise is that new technology, which appears discontinuous from the perspective of the adopting industry, often has its origins in another industry context where it has been incrementally improving over long periods. Given that potentially relevant technology exists outside an industry, why does the technology invade a new industry when it does? This model proposes that the application of technology in the new domain is driven by two factors: the technological trajectory of the new technology, and the preference trajectory in the adopting industry.

3.1 Technological trajectories

As a technology improves through incremental progress in one domain, it can eventually improve to the point that it meets the minimum performance threshold for a different domain. In Figure 2, ongoing development of the technology from industry ‘X’ might eventually result in its invasion of industry “Y.” Levinthal (1998, p.217) illustrates this “slow pace of rapid technological change” by tracing the development of wireless communication from Hertz’ original work in generating and measuring electro-magnetic waves through its application in three subsequent domains: wireless telegraphy, wireless telephony, and broadcast radio. In some cases, one technology revolutionizes a broad set of diverse industries. Bresnehan & Trajtenberg (1995) term such advances “general purpose technologies,” using the example of the transistor and its impact on industries ranging from hearing aids to CT scanners. This underlying process is similar to Christensen’s (1997) “disruptive technology,” where a
technology starts out on the periphery of an industry, but eventually improves to the point that it can satisfy the needs of mainstream customers, at which point it then disrupts the industry. This disruption occurs even though the preferences of the mainstream customers are assumed to be relatively static. By relaxing that assumption and considering the case where customer preferences change, I provide a complementary explanation for the movement of technology from one domain to another.

3.2 Preference trajectories

I define preference trajectories as periods of incremental and discontinuous changes in preferences and characterize preferences along four dimensions, each of which can experience a preference discontinuity that drives a technological transition (See Table 1).

-----Insert Table 1 about here-----

*Relevant attributes.* Building upon well-developed microeconomic theories of consumer choice, I assume that users have a given set of product characteristics they care about -- a vector of attributes in a consumer’s utility function (Lancaster 1979; McFadden 1981; Kreps 1990). The emergence of entirely new attributes or the elimination of old attributes can make a new technology preferable to the old. In this situation, although the old technology may be clearly superior to the new technology when evaluated on traditional performance criteria, it may significantly underperform on new criteria, leading to an industry-wide shift to the new technology.

*Minimum performance requirement.* For each attribute, a minimum threshold performance level exists. A product must meet that threshold level before a consumer will include it in the set of possible purchases – in other words, even consider buying the product
(Trajtenberg 1989; Adner and Levinthal 2001). Changes in this threshold value can precipitate the adoption of new technology. For instance computer users have historically placed a certain value on the capacity of internal and external storage media such as hard disk drives, floppy disks, or Zip drives. Preferences were based on the use of these devices for storing text, data, and program files. As digital imaging has become more popular and the storage of high density images has proliferated, the minimum acceptable performance threshold (in this case, a device’s minimum capacity to be considered for purchase) has increased radically, changing the relative attractiveness of alternative memory technologies.

Maximum Valued Performance. Attributes are assumed to have decreasing marginal utility, such that there is a maximum performance threshold beyond which the marginal utility to the consumer approaches zero (Meyer and Johnson 1995; Adner and Levinthal 2001). So beyond a certain level of functionality, consumers are unwilling to pay for performance improvements. Changes in the maximum valued performance can also influence technical choices. For instance, the growth of digital imaging dramatically shifts the point of diminishing marginal utility for storage devices. Levels of storage capacity that previously exceeded consumers’ willingness to pay, now have value -- a 4 gigabyte hard drive that may have seemed overkill when storing mostly programs, text, and data, is easily filled up by images.

Relative Preference for Attributes. Finally, I assume that users place different relative value on the product attributes included in the utility function. The relative importance of attributes might shift, driving technological change. Bresnehan (1989), in his longitudinal study of innovation in CAT scanners, found that the value users placed on key scanner attributes of image quality, scan time, and reconstruction time continually changed. In the early history of the automobile industry, as urban segments of the population gained experience with automobiles,
preferences moved from an emphasis on engine performance characteristics to comfort-oriented features associated with a “rolling living room” (Clark, 1985, p.246).

Why might the preferences of customers change radically? In some sense, the technological possibilities constrain customers’ preferences. Within the context of a particular dominant design, therefore, it might be difficult to imagine how customers would develop radically new preferences. I identify four possible drivers (see Table 2).

------------- Insert Table 2 about here ---------------

First, changes in the broader socio-political environment such as government regulation, legislation, political dynamics, and exogenous shocks, can significantly influence preferences. When the Sarbanes-Oxley Act added an assessment of internal controls to the reporting requirements that public firms faced, these companies then placed increased value on software control features. This preference shift applied not only to the evaluation of specialized accounting software, which had traditionally included such features, but also to general purpose software packages such as spreadsheet programs. Shocks such as the tragic events of 9/11 can also change the value given certain product attributes, in this case increasing the importance of security features across a range of categories.

Second, discontinuities often originate from changes in other parts of the customer’s overall system of use. Complex products are generally embedded in a hierarchy of systems with boundaries drawn at multiple levels (Tushman and Rosenkopf 1992; Christensen and Rosenbloom 1995; Baldwin and Clark 2000; Schilling 2000). Technological imbalances among interdependent components of a single product can direct R&D investment towards the component that acts as a bottleneck (Rosenberg 1969). Similarly, interdependencies among products in a value system can have a profound effect on the performance requirements of each
product, and thus the direction of technological change in each industry. For instance, automobiles that can travel at 200 miles per hour are not useful if the road system cannot safely accommodate them. Likewise, the willingness to pay for digital camera features is influenced by the capabilities of computer monitors, digital printers, and imaging software. Improvements in the resolution of a digital camera have limited utility if the computer monitors used to display images and the printers used to print them cannot take advantage of better performance. Given this interdependence, technological developments in one industry can clearly cause radically different preferences in another industry.

Third, as customers evolve, their preferences also change. Yates’ (1993) study of the relationship between firms in the tabulating industry and their insurance industry customers showed that the growth of insurance companies exponentially increased the complexity and scale of their information processing requirements, causing firms to consider new technology. In addition, as customers become familiar with a technology, they often discover additional uses for it that were not originally anticipated, further shifting their preferences. Yates (1993) found that once insurance firms adopted tabulating equipment and became comfortable with its initial planned use in actuarial calculations, they discovered additional uses that shifted their preferences and imposed new requirements on manufacturers. Insurance companies began to integrate data manipulation functions with their document production processes, and thus increased the value they placed on tabulators with printing and alphabetizing functions.

Fourth, producers can also proactively attempt to influence customer preferences. When developing criteria by which to evaluate a novel product, potential adopters draw analogies to classify the product into an existing category, and then transfer the evaluation criteria from the existing category to the novel one (Gregan-Paxton, Hibbard et al. 2002). Producers can
influence those analogies through advertising or other media and thus influence preferences (Moreau, Marakman et al. 2001). Firms can also influence preferences in a new product category by being first to market and thus first to define the new space for consumers (Carpenter and Nakamoto 1989). Even after a product category has been well established, preferences can shift. In the mid-1980’s, Lenscrafters, a start-up eyewear retailer, launched a media campaign to persuade customers to value service speed, specifically one-hour turnaround, an attribute that previously had not been considered important.

4. The role of preference discontinuities in the typesetter industry

Using longitudinal data from an historical study of the typesetter industry, I illustrate the model of technological evolution and its underlying constructs. Data for this study were gathered during an intensive 14-month field-based study conducted from the fall of 1993 through the winter of 1995. The core of the data consists of a comprehensive longitudinal data set covering the entire history of the worldwide typesetter industry from its inception in 1886 through 1990. It includes a complete listing of all firms that participated in the industry and all the products they introduced, including technical specifications. These data come from a combination of primary and secondary sources including company, trade association, and individual archives, field interviews, government records, as well as industry trade and scientific journals. In total, over 50 interviews were conducted, with interviews lasting from two hours to all day. Interviewees included current and ex-employees of typesetter firms, typesetter customers, industry consultants, and industry historians. Firm employees came from multiple functional areas (e.g. marketing, engineering, finance), multiple hierarchical levels, and multiple
time periods in the companies’ histories. Wherever possible, data have been cross-checked with multiple sources

For each of three major technological transitions in the typesetter industry, I first identify the sources of the discontinuous technology and show that radical technology, from the perspective of the typesetter industry, had been developing incrementally in other industries for many years. Next I examine why new technology invaded the typesetter industry when it did. I demonstrate that technological limits do not explain the timing of transitions and show instead that preference discontinuities sparked the adoption of radical technology in the typesetter industry.

Typesetting is the process of arranging text as input to the printing process. Text from a manuscript is entered into a typesetter machine via a front-end system that evolved over time from a typewriter-like keyboard to coded paper-tape to a computerized system. The typesetter’s output is then used to create a printing plate that is used by a press for high-volume printing. For many years, typesetting was accomplished manually, based on the moveable type invented by Johann Gutenberg around 1440. Attempts to automate the process date to the 1700s and, in keeping with the technology life cycle model, the early stages of the industry saw a huge variety of technological approaches to the challenge. Over 170 different prototype inventions preceded the emergence of a dominant design, the Linotype machine invented by Ottmar Mergenthaler (Legros and Grant 1916) and introduced commercially by the Mergenthaler Linotype Corporation in 1886. By 1903, machines that followed the Linotype design architecture dominated the industry.

Over the following half-century, technological change in the typesetter industry came incrementally, extending the linotype architecture. The industry has since been shaken by three
waves of radical, competence-destroying technological change. Each new generation of technology was accompanied by significant new entry into the industry, although only in the first transition did new entrants gain significant share (See (Tripsas 1997) for a discussion of the competitive implications of new technology). Table 3 summarizes the technological differences between the four typesetter generations. In the following section I analyze the transitions between these generations, illustrating the influence of the interplay between technological trajectories and preference trajectories on the nature and timing of technological discontinuities.

-------- Insert Table 3 about here  ---------

4.1 Transition one: from hot metal to analog phototypesetters

Discontinuous technological change first shook the typesetter industry in the form of analog phototypesetters in 1949. While the competitive effect of this shift was dramatic, the basic technology developed gradually, occurring outside the industry over a long period of time. Optical systems, including lenses and film, were imported from the photography industry, where significant technological progress had been made in the 1940s (Jenkins 1975). Kodak even served as a consultant to typesetter firms in the development of early machines. Stepping motors and electronic strobe lights in the new phototypesetters came from prior military applications, and the telecommunications industry contributed electro-mechanical relays that were originally developed for central office switches. Thus, however radical these technologies may have seemed to the typesetter industry, they merely applied well-established technology that had been developing over an extended period in other domains (See Table 4). The reliability and cost-
competitiveness of these technologies had improved over time, but this improvement did not coincide with their application in typesetters.

Given that new technology was imported from other industries, what factors affected the adoption’s timing? Was the new technology needed to overcome limits to the previous Hot Metal architecture? An examination of the technology performance S-curve shows that this is not the case; exhaustion of the existing technology does not explain the timing. Figure 3 shows the output speed of each new hot metal machine introduced into the typesetter industry from 1886 through 1967. Speed, measured in characters per second (cps), was chosen since this was a primary purchase criterion across all typesetter buyers and had been used in technology forecasting studies for the industry (Mohn 1971). Interviews with industry participants active during the period reveal that users had not yet reached a point of diminishing marginal utility; they still placed significant value on increased speed.

Interestingly not one, but two technology S-curves appear to be operating over this timeframe. After an initial period of ferment and improvement, speed remained constant from 1910 to 1939. At that point, we see another S-curve began as speed once again increased significantly between 1940 and 1965.

This second S-curve appears to be quite consistent with the observation that, when threatened by a new technology, the old technology often undergoes a last gasp of innovation in an attempt to compete (Gilfillan 1935; Utterback 1994). The difference is that this last gasp lasted 25 years and provided a greater increase in speed than had been accomplished in the prior 50 years of hot
metal incremental innovation. The magnitude of this improvement hardly seems like one last
tweak to a technology that has reached its natural limit. In fact, the level of improvement makes
one question whether the change was, in fact, incremental. An examination of product design
records, however, indicates that the new models’ biggest innovations were incremental changes,
including the continuous assembly of letter molds and the use of hydraulics to justify text. When
the development of hot metal typesetters was set aside in the 1970s, engineers at Mergenthaler
Linotype, still the leading producer, had already developed plans that doubled a hot metal
machine’s speed yet again. The hot metal technology was far from its limits when the invasion
of analog phototypesetters began in 1949.

--------- Insert Table 5 about here ---------

Instead, I argue that the technological shift was driven by a preference discontinuity (see
Table 5). Specifically, a shift in the broader printing value system created a preference
discontinuity in the typesetter industry. In the early 1900’s, newspapers were the primary users
of typesetters, and speed was the machines’ most critical attribute, as papers tried to scoop each
other with the most timely stories. Gradually, newspapers began to incorporate more graphics
and pictures (vs. text) as they tried to differentiate their products. In addition, according to the
Census of Manufacturers, printing and publishing of periodicals and books had grown to 45% of
the printing and publishing industry’s total output by 1939, and graphics and pictures were an
important component of this market. This increased the adoption of a new printing technology,
offset lithography, which was much better suited to the printing of images than was traditional
letterpress printing. By 1950, offset printing accounted for about 5% of the printing market, and
sales of offset printers were growing at about 30% per year.
Given the interdependence between typesetters and printers, the movement to offset printing imposed a new minimum feature for typesetters – the ability to produce a film interface. In contrast to letterpress printers which used raised metal characters, offset printers required film as input to create a printing plate. While a hot metal typesetter could meet this need, the process was quite cumbersome in contrast to using an analog phototypesetter. A hot metal machine created just one ink impression of the resulting raised letters, and that impression was then photographed (see Figure 4). Louis Moyroud and Rene Higonnet, the developers of the first mechanical phototypesetter, the Photon, recognized the mismatch between hot metal typesetters and offset printers:

"Our history begins in Lyon, toward the end of the war, in June of 1944. I was at that time an engineer at the information and patents department of an important subsidiary of a large American corporation. Mr. Higonnet was the regional manager of this department. We were asked to publish a French patent gazette in the most economical manner. Knowing practically nothing about printing, Mr. Higonnet went with one of our associates to visit a printing firm in Lyon specializing in offset printing. They explained to him the operation of a Linotype. He was told that, in order to prepare a plate for offset printing it was necessary to cast lines of type, lock them in chases, set them up on the press and then produce only one good repro proof. Mr. Higonnet has always been interested in photography and his reaction was immediate: there should be a market for a photographic type composing machine. 'Why, he said, don't we make a photographic type composing machine?' The idea seemed simple to me. 'Why not,' I said, 'let's go ahead.' And so, in the month of June 1944, we committed ourselves to a task that was to change our lives." (transcript of a Moyroud speech from late 1960’s)

The interaction between technological progress and preferences continued with the new technology, which aroused interest from an additional market segment. Once analog phototypesetters were available, the pool of typesetter customers expanded to include in-house publishers – functional groups within a corporation that did typesetting and printing for internal publications. These customers had minimum performance requirements for safety and noise –

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requirements that the prior generation of hot metal typesetters could not meet. Although in-house publishers were not early adopters of phototypesetters, firms began to purchase them since the new machines met their minimum requirements. The preferences of this new office segment then began to influence technological developments. For instance, office employees were trained on and “locked into” the QWERTY keyboard configuration as evidenced by the inability of the demonstrably superior Dvorak keyboard layout to gain market inroads (David 1985). Although hot metal typesetters had incorporated their own different “SHRDLU” keyboard layout for over 50 years, once the in-house office segment became part the customer network, the preference of that segment for a QWERTY layout was strong enough to drive the typesetter keyboard’s shift to QWERTY in the analog phototypesetter generation. Analog phototypesetter preferences subsequently evolved incrementally until changes in the broader system of use triggered the next preference discontinuity and the movement to CRT phototypesetters.

4.2 Transition two: from analog to CRT phototypesetters

In the transition to CRT (cathode ray tube) phototypesetters, most of the machine’s moving parts disappeared as electronics substituted for electro-mechanical technology. Characters were magnetically stored as a digital series of start/stop points, and a vertical CRT scan “wrote” the character’s image. Once more, this technology was adapted from other industries (See Table 4). As early as 1946, Mergenthaler Linotype had explored using CRTs in typesetting, but the resolution was too low to achieve typographic quality (Corrado 1965). By the early 1960s, however, high-resolution CRTs appeared, developed for applications such as aerial reconnaissance photography. These CRTs were beginning to make their way to the graphic arts with some firms adapting CRTs to digital image scanners. CRT phototypesetters
also appropriated developments in the computer industry, such as programmable mini-computers, software, magnetic tape, and hard disk drives for the storage of fonts. By the time they were incorporated into typesetters in the 1960s these technologies had made significant incremental progress in other application domains.

Technological limits, once again, do not explain the timing of the transition from analog to digital CRT phototypesetters. The first CRT phototypesetter was announced in 1965, at a point when analog phototypesetters had yet to even begin the steep part of their technology S-curve (see Figure 5). The introduction of new analog models diminished around 1975 due to the substitution of CRT machines, also long before the technology reached any limits.

I argue that once again, the transition was precipitated by a preference discontinuity; a shift in the marginal utility of extremely high levels of speed. In the analog phototypesetter generation, the value of additional typesetter speed was limited by the speed of the data input method, whether a human operator or a paper tape. Radical increases in output speed would not have had value. By the early 1960s however, many companies used computers for data processing. Large databases were usually printed on low-quality, high-speed line printers. Typesetting items from these databases, such as telephone directories or catalogs, was an excruciatingly slow process, as the maximum output speed of the analog phototypesetters was only 100 characters per second compared to 1,000 characters per second for computer line printers. The proliferation of computer databases in electronic format created demand for a significantly faster typesetter that could handle a rapid stream of magnetic tape input. A 1969 industry report (Auerbach Information 1969) stated,
“No consideration of photocomposition would be complete if it failed to mention the stimulus afforded by the phenomenal growth of electronic data processing and the need to rationalize the method of publishing its output.”

Alphanumeric, one of the first firms to develop a digital CRT phototypesetter, explicitly targeted the electronic data processing market. An informational financial offering brochure in May 1964 stated,

“Alphanumeric’s potential market is the portion of the $1.5 billion typesetting market that produces non-creative and repetitive information for printing and publishing. Estimates indicate that typesetting for all of the AT&T Telephone Directory pages alone accounts for $24 million per year...No high speed graphic art quality phototypesetter … is presently available...Alphanumeric intends to … develop a working high-speed photocomposer of its own design. It is anticipated that this unit connected to a general purpose computer, will provide the necessary hardware for the company to initiate a photocomposition service for the printing and publishing industries.”

The shift to magnetic tape input thus created a preference discontinuity, a step function change in the value of high levels of output speed, which triggered a technological discontinuity.

4.3 Transition three: from CRT to laser imagesetters

Just as advances in computerized data processing drove the shift to high speed CRT typesetters, continual advances in computerized front-end systems created another preference discontinuity: the need to integrate text and graphics (See Table 5). This change drove the industry’s transition to laser imagesetters. Throughout the 1970s, multi-terminal front-end computer systems had been developed to take advantage of the high-speed output of CRT typesetters. Newspapers installed systems that allowed reporters to enter stories at their own remote terminals, with editors accessing the work in centralized storage. These systems aimed to produce complete pages of integrated text and graphics. Such a system would eliminate the time-consuming process of “stripping,” where images and galleys of text were manually arranged and secured on pages. The stripping process had continued through both the analog phototypesetter and CRT generations. In 1975, a start-up firm, Camex, announced a system that made major
progress towards the goal of automated integration. It incorporated a graphic tablet linked to a video screen. The layout blocks that an operator sketched with a stylus on the tablet appeared on the screen. In 1977, Xenotron, a British firm, announced a Video Composer that allowed WYSIWYG (What You See Is What You Get) output. Since these front-end systems could now provide full page integrated input, the ability to create full pages of integrated text and graphics on a typesetter became valuable.

The first laser imagesetter introduced in 1976 met this new requirement. By using raster image processing software to write lines across a page with a laser, this machine produced full pages of both text and graphics. The enabling technology was once again found outside the industry (See Table 4). In the early 1970s, firms such as Cognitronics and ECRM had used helium-neon lasers in OCR (Optical Character Recognition) scanners. These lasers were also applied to consumer electronics, particularly the failed introduction of video discs, further spurring their development. In order to cut costs, later imagesetter models began to use laser diodes, which were also originally developed for consumer electronics. Much of the software in laser imagesetters also came from outside the industry. Postscript, the dominant imagesetter raster image processing (RIP) software for both manipulating characters and writing out pages was developed by Adobe Systems, a start-up company focused on desktop publishing. Postscript was an extension of a previous technology, Interpress, which had been under development at Xerox for some time.

As with prior technological transitions, the introduction of laser imagesetters seems to bear no relation to the approaching limits of CRT machines in either of two crucial dimensions: speed and quality. Figure 6 plots the speed of CRT machines over time and shows no clear S-curve pattern. In fact, later models at lower speeds were being introduced, indicating that the
technology had exceeded the speed requirements of at least some customers. Figure 7 shows the resolution of each machine introduced to gauge the quality of the letters being produced over time. Again there is not evidence of an S-curve.

Thus in each of the typesetters’ technological shifts, radical changes in user preferences—preference discontinuities—precipitated the movement to a new generation of technology. These preference discontinuities resulted in the adoption of new technology from other industries. This new technology was discontinuous and competence-destroying in the context of typesetters and had significant competitive implications, but from the perspective of the source industries the new technology was not radical at all.

Another interesting aspect of this history relates to those firms that first applied the new technology in the typesetter industry. In both the first and second transitions, start-ups founded by typesetter users were the first to introduce new products. The first electro-mechanical phototypesetter, the Photon, was invented by two individuals who worked in a patent office and were frustrated by the awkwardness of their user experience. The first CRT phototypesetter was designed by a service bureau, Alphanumeric, that used the machine to provide typesetting services, and another early CRT machine was invented by two ex-printers. Just as lead users have been shown to better understand customer needs for new technologies (von Hippel 1987; Urban and von Hippel 1988), these “user entrepreneurs” (Shah and Tripsas 2004) may have had a better understanding of emerging preferences driven by their own experience.

6. Discussion and Conclusions
The technology life cycle literature provides strong theoretical foundations that explain how an era of technological ferment culminates in a dominant design, as well as how technology progresses during the resulting era of incremental change. But the processes by which subsequent technological discontinuities occur, particularly their timing, remains relatively unexplored. What factors cause a discontinuous technology to invade a particular industry when it does? This paper develops a model of technological evolution that incorporates both technological trajectories and a new concept: preference trajectories, cycles of incremental and discontinuous change in preferences. It points to the important role of preference discontinuities in triggering industry technological transitions.

Preference discontinuities take two forms: the addition of entirely new attributes to the set of factors a customer values, and step function changes in the valuation of existing performance attributes. In either case, new preferences change the value provided by the old technology relative to new technology, making the new technology viable in the industry. Preference discontinuities can result from a wide range of drivers including: shifts in the broader socio-political environment, interdependencies with changing products in the customer’s overall value system, customer growth and learning, and proactive, strategic moves on the part of producer firms.

The model is illustrated with an in-depth study of 100 years of typesetter history, during which the industry underwent three major technological transitions. In each case, technology that appeared radical from the perspective of the typesetter industry was imported from other contexts where it had been developing incrementally for long time periods. The movement of the technology from other domains into typesetters in each of the three transitions was sparked by preference discontinuities – radical shifts in the preferences of typesetter users.
This paper contributes to the technology life cycle literature by extending our understanding of an industry’s movement from maturity back to a period of technological ferment. The existing literature provides two explanations for the invasion of new technology: 1) the old technology reaches its performance limits, necessitating new technology for additional improvement (Sahal 1985; Foster 1986; Fleming 2001), and 2) new niches with different needs emerge, enabling the new technology to enter the industry in the niche and eventually improve to the point that it meets mainstream needs (Christensen 1997; Adner 2002). In each of these cases, during periods of maturity, preferences of existing customers remain stable. This paper provides a fundamentally different, but complementary alternative for technological transitions – mainstream preferences shift radically and require new technology if they are to be met.

While the model presented adds richness to our understanding, it has clear limitations, providing opportunities for future research. The model assumes that a consumer’s preferences are not influenced by the context at the moment of purchase. The marketing literature has shown the importance of anchor points in consumer behavior, documenting in experimental settings how different anchor points affect a consumer’s willingness to pay (Johnson and Schkade 1989; Green, Jacowitz et al. 1998). Preferences may also be conditioned on the consumer’s initial endowment, with loss aversion a strong experimental finding (Tversky and Kahneman 1991; Bateman, Munro et al. 1997). Future research might examine the implications of reference-dependent preferences for technological change. The model also does not explicitly consider the role of heterogeneous preferences. Preference discontinuities may be restricted to just a few market segments, or some segments may experience them sooner than others. In this case new technology may enter the industry only in one segment or diffuse slowly throughout the population.
How generalizable is the concept of preference discontinuities? Although the detailed empirical data presented derive from a single industry, examples from other industries provide some supporting evidence. Most of these examples, however, are for complex assembled products. Future work that examines this and other technology life cycle phenomena in service industries or non-assembled product industries would be welcome. In addition, not all preference discontinuities result in technological change. In some cases producers can respond to changing preferences by adapting existing products. Airline deregulation in the US made hub-and-spoke systems both feasible and attractive to airlines. With these new routing systems, airlines’ preferences for planes changed significantly. Multiple short flight legs substituted for single long haul routings, making a plane’s range less valuable. Smaller planes that were efficient over short distances became more attractive. This shift in preferences, however, did not require fundamentally new technology; it simply gave an advantage to certain types of planes. Airline preferences for airport terminal configuration also changed with deregulation. To accommodate passengers that were changing flights, gates needed to be closer together. The configuration of existing airports had not been optimized for hubs. The architecture of airport terminals built after deregulation made gates closer together, for instance placing terminals in a circular as opposed to linear arrangement. Again, meeting these new preferences required a different solution, but not fundamentally different technology.

What are the competitive implications of preference discontinuities? Established firms have for the most part lost market leadership to new entrants when confronted with radical technological change (Cooper and Schendel 1976; Majumdar 1982; Tushman and Anderson 1986; Henderson and Clark 1990; Utterback 1994). Are some firms better positioned to take advantage of change triggered by preference discontinuities? In the typesetter industry, users
both recognized the opportunities created by the preference discontinuities and took advantage of them by commercializing their innovations. These user entrepreneurs were highly successful given their unique understanding of needs. While some research has shown the potential significance of users as a source of entrepreneurial activity (Shah 2003; Shah and Tripsas 2004; Shah 2005), empirical work relating user entrepreneurship to the technology life cycle would be a useful extension.

If firms can proactively shape preferences, driving preference discontinuities, what mechanisms are most effective? And if firms can influence what attributes are valued, how can they influence the manner in which those attributes are measured? In the mid-1980s, the established metric for evaluating the speed of a mainframe computer was MIPS (million instructions per second). IBM actively attempted to persuade customers that an alternative measure, “throughput,” made more sense. Throughput, a quality at which IBM excelled, was a system-level measure that took into account not only processor speed, but communications bottlenecks. Similarly, early in the history of the flash memory card industry, LexarMedia successfully defined measures of card speed in a digital camera to its advantage (Staudenmayer, Tripsas et al. 2005). The emerging research stream in institutional entrepreneurship, which examines how firms can influence their institutional context, begins to lend insight into these issues (DiMaggio 1988; Aldrich and Fiol 1994; Garud, Jain et al. 2002). For instance, the institutional context can profoundly affect the routines and metrics used to evaluate new technologies (Garud and Rappa 1994). While existing work in this area is promising, more is needed to understand how this process unfolds.

By relaxing the assumption that customer preferences are static, this paper has provided new insight into the complex relationship between demand and technological evolution. But it is
a first step in unraveling the complicated interplay among preferences, technology, and competition. I hope that this work will inspire future research that incorporates changes in the demand environment into our theories of technological evolution.
Table 1
An Overview of Preference Trajectories

<table>
<thead>
<tr>
<th>Dimensions of Demand</th>
<th>Relevant Attributes</th>
<th>Minimum performance requirement for an attribute</th>
<th>Maximum valued performance for an attribute</th>
<th>Relative preference for attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Incremental Change in Preferences</strong></td>
<td>Customers evaluate products based on a stable set of attributes</td>
<td>Minimum performance requirements remain relatively constant</td>
<td>The point at which marginal utility of an attribute approaches zero remains relatively constant</td>
<td>Relative preference for different attributes remains stable</td>
</tr>
<tr>
<td><strong>Preference Discontinuity</strong></td>
<td>New attributes are considered or old attributes eliminated in evaluating a product</td>
<td>Radical increase or decrease in minimum performance required for an attribute</td>
<td>Radical shift in point at which marginal utility approaches zero</td>
<td>Radical shift in relative preferences</td>
</tr>
</tbody>
</table>

Table 2
Drivers of Preference Discontinuities

<table>
<thead>
<tr>
<th>Shifts in the socio-political environment</th>
<th>System-level interdependencies</th>
<th>Evolution of Customers</th>
<th>Strategic Action by Producers</th>
</tr>
</thead>
</table>
| - Government Regulation/Legislation  
  - Pollution control  
  - Sarbanes-Oxley  
- Political change  
  - Opening of borders in Eastern Europe  
- Exogenous shocks  
  - Terrorist events, e.g. 9/11 | - Shifting performance bottlenecks  
  - Digital cameras, computer monitors and printers | - Increase in customer size/complexity  
  - Customer scale shifts requirements, e.g. insurance industry  
- Learning / experience  
  - Discovery of new uses for cars | - Media  
  - Advertising  
  - Public relations  
- Institutions  
  - Standards bodies that set performance metrics |
### Table 3
Comparison of Typesetter Technological Generations

<table>
<thead>
<tr>
<th>Generation (year introduced)</th>
<th>Machine Characteristics</th>
<th>Controlling Machine Logic</th>
<th>Escapement (spacing of characters)</th>
<th>Font Format</th>
<th>Character Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Metal (1886)</td>
<td></td>
<td>Mechanical</td>
<td>Mechanical</td>
<td>Metal</td>
<td>Hot Metal</td>
</tr>
<tr>
<td>Analog Phototypesetter (1949)</td>
<td>Electro-mechanical</td>
<td>Mechanical</td>
<td>Film</td>
<td>Film</td>
<td>Xenon Flash</td>
</tr>
<tr>
<td>Digital CRT phototypesetter (1965)</td>
<td>Electronic/software; programmable minicomputer</td>
<td>Mechanical / electronic</td>
<td>Digital start/stop pattern</td>
<td>CRT strokes</td>
<td>CRT strokes</td>
</tr>
</tbody>
</table>

### Table 4
The Source of Discontinuous Technology in Typesetters

<table>
<thead>
<tr>
<th>Technology Generation</th>
<th>New Technologies</th>
<th>Source Industries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog Phototypesetters</td>
<td>• Optical systems</td>
<td>• Photography</td>
</tr>
<tr>
<td></td>
<td>• Film</td>
<td>• Telecommunications</td>
</tr>
<tr>
<td></td>
<td>• Electro-mechanical relays</td>
<td>• Military</td>
</tr>
<tr>
<td></td>
<td>• Stepping motors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Electronic strobe lights</td>
<td></td>
</tr>
<tr>
<td>Digital CRT Phototypesetters</td>
<td>• CRT tubes</td>
<td>• Military</td>
</tr>
<tr>
<td></td>
<td>• Embedded minicomputers</td>
<td>• Computers</td>
</tr>
<tr>
<td></td>
<td>• Magnetic storage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Software</td>
<td></td>
</tr>
<tr>
<td>Laser Imagesetters</td>
<td>• Lasers</td>
<td>• Consumer electronics</td>
</tr>
<tr>
<td></td>
<td>• Image processing software</td>
<td>• Computers</td>
</tr>
</tbody>
</table>
Table 5
Preference Discontinuities in Typesetters

<table>
<thead>
<tr>
<th>Technological Transition</th>
<th>Preference Discontinuity</th>
<th>Driver of Preference Discontinuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot metal to analog phototypesetter</td>
<td>New attribute: Ability to produce film</td>
<td>System Interdependency: Offset Printing</td>
</tr>
<tr>
<td>Analog phototypesetter to digital CRT phototypesetter</td>
<td>Radical shift in the marginal value of high speed</td>
<td>System Interdependency: Electronic Data Processing Input</td>
</tr>
<tr>
<td>Digital CRT phototypesetter to laser imagesetter</td>
<td>New attribute: integration of text and graphics</td>
<td>System Interdependency: Front-end Systems supporting integrated text and graphics</td>
</tr>
</tbody>
</table>

Figure 1
The Technology Life Cycle Model

Era of ferment
• Design competition
• Substitution

Era of incremental change
• Elaboration of dominant design

Technological Discontinuity 1

Forces Driving the Dominant Design
• Socia
• Political
• Institutional
• Economical

Forces driving Technological Discontinuity 2
• Technological limits inherent in dominant design
• Exogenous technological shocks

Adapted from Abernathy & Utterback, 1978; Anderson & Tushman, 1990
Figure 2
An integrated model of technological transitions: the role of preference discontinuities

-- Diagram --

Technology from industry “X”

Technological trajectory in industry “X”

Industry “X” technology improves incrementally until it meets the performance criteria of industry “Y”

Preference trajectory in industry “Y”

Preference Discontinuity in the form of:
- New attributes
- Radical increase in minimum performance required for an existing attribute
- Radical shift in maximum performance valued for an existing attribute
- Radical shift in relative preferences across attributes

Technological Discontinuity in the context of industry “Y”
Figure 3
Hot Metal Typesetter Speed, 1886-1967

Next-generation analog typesetter introduced (1949)
Figure 4
A Comparison of Typesetter / Printing Interfaces

Hot Metal typesetting and Letterpress Printing

- Set type using hotmetal linecaster
- Photoengrave images
  - Arrange type and images in frame
  - Ink Frame and print

Awkward Interface between Hot Metal typesetting and Offset Printing

- Set type using linecaster
- Arrange type in frame
- Ink frame and print one copy
  - Photograph text and develop film
  - “Strip” together text and images
  - Create printing plate and print
  - Photograph image and develop film

Phototypesetting and Offset Printing

- Set type using phototypesetter
  - Photograph image and develop film
  - “Strip” together text and images
  - Create printing plate and print
Figure 5
Analog Phototypesetter Speed, 1949-1982

Next-generation CRT machine introduced (1965)
Figure 6
CRT Phototypesetter Speed, 1965-1987

Figure 7
CRT Phototypesetter Resolution, 1965-1987
References


