Surviving Radical Technological Change:
An Empirical Study of the Typesetter Industry

by

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To my parents
with love

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ABSTRACT

The need to adapt to changes in the external environment poses major challenges for many incumbent firms. Radical changes in technology can prove especially difficult to manage, with numerous examples of new entrants displacing incumbents in industries transformed by new technology.

While a great deal of research has enriched our understanding of incumbent failure when managing technological transitions, much less emphasis has been placed on understanding incumbent success. This dissertation addresses this gap. Through an empirical study of over 100 years of history in the typesetter industry, it explores how some firms founded in the late 1800s are still prospering today despite four radical shifts in technology.

This study integrates organizational and economic perspectives on technological change and suggests that isolating the impact of a technological shift on both current technological competence and other economic barriers to entry unmasks key factors affecting incumbent survival. Quantitative analysis shows that by exploiting barriers to entry that are not affected by a competence-destroying technological shift -- such as reputation advantages or sunk cost investments -- incumbents are buffered from competition and can succeed despite developing new technological capability at a slower rate than potential new entrants.

Some incumbents, however, are systematically superior to others in developing new technological capabilities. Quantitative analysis is therefore complemented by detailed case studies that explore differences among incumbents. The ability to identify and integrate external knowledge in a new technological domain differentiates the more successful incumbents. In particular, the ongoing utilization of an external communication infrastructure contributes to the absorption of external technological knowledge.

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Contents

Chapter One: Introduction

Chapter Two: Literature Review and Hypothesis Development

Chapter Three: Research Methods and Data

Chapter Four: Technological Change in The Typesetter Industry

Chapter Five: The Effect of Technological Change on Barriers to Entry

Chapter Six: Descriptive Data on Entry and Performance

Chapter Seven: Quantitative Analysis of Entry and Performance

Chapter Eight: Integrating External Technological Knowledge: Case Studies

8.1 Introduction

Chapter Nine: Discussion And Conclusions

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Chapter One
Introduction

1.1 Overview

Industry evolution is often unkind to incumbents. As industries change, incumbents frequently have difficulty adapting their existing capabilities to meet the demands of a new competitive landscape. Radical changes in technology can prove especially difficult to manage, with numerous examples of new entrants displacing incumbents in industries transformed by new technology. For instance, the advent of electronic calculators, diesel-electric locomotives, jet engines and solid state semiconductors each enabled new entrants to overthrow entrenched competitors. (Cooper & Schendel, 1976; Madumjar, 1984; Foster, 1986).

A great deal of research has enriched our understanding of why incumbents fail to successfully manage such transitions. First, incumbents may perceive less incentive to invest in new technologies that cannibalize existing products (Reinganum, 1983; Ghemawat, 1991). By the time it becomes apparent that the incumbent must invest, new entrants may have an irreversible lead. Administrative factors may also be responsible for a lack of investment. When a radically new technology creates a new set of customers with different needs, incumbents may be too focused on the needs of their existing customers to recognize the potential of the new technology. In the disk drive industry, for instance, incumbent firms consistently failed to invest in technologies targeted at new customer segments (Christensen, 1993). Finally, even if an incumbent makes a significant investment in new technology, organizational factors may preclude successful development of new technological capability. Existing routines and procedures fine-tuned to fit with the old technology may be difficult to change (Nelson & Winter, 1982; Tushman & Anderson, 1986; Henderson & Clark, 1990).

Much less emphasis has been placed on understanding situations where incumbents are successful at managing technological transitions, despite the fact that these "exceptions" are not all that uncommon. For instance, many incumbent firms in the telephone central office switch industry survived a competence-destroying shift from electro-mechanically controlled switches with relay logic to digital electronic computerized switches with stored program control. Other examples where incumbents have experienced success with radically new technologies include float glass, synthetic fibers, CT scanning and electronic cash registers. (Rosenbloom & Christensen, 1994).

The goal of this dissertation is to deepen our understanding of the underlying factors driving incumbent success in the face of radical technological change. Through an empirical study of 107 years of history in the typesetter industry, this dissertation examines how some firms founded in the late 1800s are still prospering today despite four radical shifts in technology. Beginning with the invention of the hot metal Linotype machine in 1886, it analyzes the nature of technological change in the industry and the organizational and competitive implications of that change. Data on the relative performance of incumbents vs. new entrants is combined with detailed firm case studies in order to understand both industry-level patterns of competition and internal organizational factors responsible for incumbent survival.

Two complementary explanations for incumbent success are identified. First, to understand why incumbents in general might survive competence-destroying technological change, it argues that one must look beyond just the effect of the change on a firm's current capabilities to also understand how it affects the broader industry structure -- specifically other economic barriers to entry. Descriptive statistics as well as models of entry and market share show that by exploiting barriers to entry that are not affected by a competence-destroying technological shift -- such as reputation advantages or sunk cost investments -- incumbents are buffered from competition and can succeed despite developing new technological capability at a slower rate than potential new entrants. In addition, the quantitative analysis demonstrates the danger of considering only a single perspective. Effects which at first blush appear to be the result of competence-destruction are sometimes actually the result of other barriers to entry. Without controlling for other barriers to entry, results can thus be misleading.

Second, even if an incumbent is temporarily buffered from competition, it must still eventually develop new technological capabilities. The lower the protection from barriers to entry, the more urgent the ability to adapt becomes. The question, "How have certain incumbents systematically outperformed others when adapting to radical shifts in technology?" is therefore also addressed. The goal is to better understand what Teece, Pisano & Scheun call: "dynamic capabilities...the capacity of a firm to renew, augment, and adapt its core competencies over time." (1992, p.18). This goal is addressed through a comparison of technological transitions and product development efforts at Mergenthaler Linotype, Monotype, Intertype, and Compugraphic. The first three firms dominated the industry from the late 1800s through the first shift in technology. Of these three, Mergenthaler Linotype is the only one to successfully traverse all four subsequent generations of technology. Compugraphic was the most successful new entrant in the industry.

A comparison of these firms suggests that the ability to identify and integrate external knowledge in a new technological domain -- i.e. a firm's ability to develop *new* absorptive capacity (Cohen and Levinthal, 1990) -- is critical to surviving competence-destroying technological change. Since radical technological change generally originates outside the industry, firms within the industry must have some explicit means both for scanning the environment to be aware of technological developments and then for integrating those developments. Mechanisms for accomplishing this can take a number of forms. In particular, the ongoing utilization of an external communication infrastructure was found to contribute to the absorption of external technological knowledge.

1.2 Structure of the dissertation

The dissertation is structured as follows. In Chapter Two I review and integrate two sets of relevant literature in order to develop a framework and hypotheses about incumbent survival: 1) the innovation literature on technology life cycles and technological competence, and 2) the economic literature on barriers to entry. The innovation literature generally holds that during periods of incremental competence-enhancing change, established firms develop strong organizational capabilities related to the existing technology. New entrants therefore find it very difficult to establish a position in the industry. When there is a radical or competence-destroying shift in technology, however, incumbents have trouble adjusting, and new entrants often take over industry leadership. An implicit and sometimes explicit assumption of this literature is that a shift which destroys competence also destroys barriers to entry. I argue that this is not necessarily the case, and by reviewing the economic literature on barriers to entry, I identify certain types of barriers which can move independently of current competence. By thinking about these other barriers to entry as distinct from barriers based on current competence, I develop a framework and hypotheses regarding incumbent survival. As discussed above, when other barriers remain high despite the destruction of competence-based barriers, then incumbents have a higher likelihood of performing well.

In Chapter Three I describe the data and methods used to test these hypotheses. Through in-depth field work in the typesetter industry involving an examination of archival records, books and journals going back to the late 1800s, as well as over 50 interviews, I have developed a comprehensive longitudinal data set covering the entire history of the worldwide industry from 1886 through 1993. This data set includes the size and growth of the industry, entry and exit dates of every firm in the industry as well as detailed data on every product ever introduced by these firms, including product price, sales and performance characteristics. This data is supplemented by internal organizational data about a subset of firms.

Chapter Four gives a detailed history of technological change in the typesetter industry. I describe the origins of the industry and how the hot metal Linotype linecaster architecture came to dominate the industry despite a great deal of initial technological variation and competition. I then analyze the evolution of each of the four subsequent generations of technology. Several common themes emerge from this analysis. First, most technology used in the industry did not originate inside the industry. Instead, technological advances in other industries such as electronics and computers had a profound impact on typesetters. Generally new entrants introduced the new technology to the industry. Second, user innovation and user financing of innovation played a vital role in the industry. Users were involved in the original automation of typesetting as well as in initiating the second and third generations of technology. Finally, changing user needs, often a result of changes in other parts of the printing value system, guided the direction of technological change in typesetters.

Given the description of technological change in Chapter Four, Chapter Five places each generation of typesetter technology in the framework outlined in Chapter Two -- each generation is evaluated in terms of its effect on current competence and other barriers to entry. An analysis of the skills required in each generation as well as product architecture is used to categorize a technology as competence-destroying or not. An examination of minimum efficient manufacturing scale, sunk cost investments in a font library, reputation and product compatibility is used to determine whether other barriers to entry are destroyed.

Chapter Six provides descriptive data in support of the arguments made in Chapter Two. Basic data on entry and entrant market share for each generation of technology support the conclusion that incumbents are being buffered by other barriers to entry when facing competence-destroying technological change. In particular, the large sunk cost investments in font libraries provided incumbents a shield from competition. The time and investment necessary for a new entrant to replicate such a library was difficult to justify given the size of the market.

Chapter Seven quantitatively tests the intuition developed in Chapter Six. I examine the determinants of both rates of entry into the industry and the market share obtained by new entrants. I distinguish between competence-based factors and other barriers to entry and find that by examining only the effects of competence-destruction, without controlling for the destruction of other barriers, results can be misleading. I also find that in this industry, other barriers to entry appear to play a stronger role. Given a competence-destroying technological shift, incumbents are more likely to maintain their market position when other barriers remain strong as opposed to when they too are destroyed. Other barriers do indeed appear to be buffering firms from competition, giving them a chance to develop new technological capabilities.

Despite the fact that they are buffered, established firms must eventually develop new technological capability in order to survive. Chapter Eight examines a subset of case study firms in order to draw some preliminary conclusions about how best to develop new capability. Early investments in acquiring external knowledge appear to play a key role in making successful transitions. Firms with a strong culture of external technology acquisition and established external communication structures were more successful at recognizing the need to make those investments and at then establishing effective linkages with external knowledge sources.

Finally, I conclude with an exploration of theoretical and managerial implications as well as suggested directions for future research.

Chapter Two

Literature Review and Hypothesis Development

A great deal of work has analyzed the relationship between technological change and the competitive position of incumbents and new entrants. In this chapter I review two distinct streams of relevant literature: the innovation literature on technological competence and the economics literature on barriers to entry. By integrating these two perspectives, I then develop a framework and hypotheses related to the expected performance of incumbents and new entrants given different types of technological change.

2.1 Innovation and technological competence

Technological progress in an industry is generally characterized as passing through long periods of incremental innovation punctuated by periods of radical change (Abernathy & Utterback, 1978; Dosi, 1982; Sahal, 1985; Tushman & Anderson, 1986). Dosi likens this pattern to Kuhnian theories of the development of new science. A technology develops incrementally along a given "technological trajectory" within a given "technological paradigm" until it is replaced with a new paradigm -- a radical innovation. Abernathy and Utterback describe stages of this "technology life cycle." The initial stages of a new paradigm exhibit a "fluid pattern." During this stage there is a great deal of uncertainty as to how the new technology will be embodied in a product, and there are often competing designs. Eventually one dominant design emerges and at that point, after a transitional stage, a "specific pattern" begins. Product innovation is incremental within the constraints of the dominant design, and the emphasis is on achieving more efficient means of production. This stage continues until the emergence of another radical innovation.

Different stages of the technology life cycle have major implications for the competitive positioning of incumbents and new entrants. During an incremental period, when technological innovation builds upon the capabilities of established firms, it is "competence-enhancing," and established firms have an advantage over new entrants. Given a stable technological environment, established firms invest in organizational structures that enable them to efficiently process information within that environment (Burns & Stalker, 1966; Galbraith, 1973; Arrow, 1974). Over time they establish organizational routines and procedures that codify their existing technological knowledge (Nelson & Winter, 1982). These routines and procedures become embedded in the communication patterns and information filters that feed the problem solving activities of the firm and make the firm more efficient in the context of the existing technological regime. The cumulative knowledge of an established firm is hard for a new entrant to duplicate, making entry difficult.

When faced with a competence-destroying shift, however, established firms are often at a disadvantage. In some cases, these firms lack the incentive to invest in developing new technological capabilities (Reinganum, 1983; Ghemewat, 1991). Even if the firm has the incentive to invest, management may not recognize the need. When the customer base and customer needs shift along with the technology, then established firms focused on their existing customers may not feel the new technology is relevant enough to invest in it (Christensen, 1993; Rosenbloom & Christensen, 1994).

Even if an established firm does invest significant amounts in a new technology, existing competencies often inhibit the firm's development of new capabilities. I use Henderson's definition of a competence-destroying shift as one that "requires the firm to process quite different kinds of information. The information filters and organizational procedures and routines that have developed through the firm's experience with a sequence of incremental innovations founded upon quite different scientific or technological principles become partially obsolete." (Henderson, 1993, pp. 251-252). When faced with such a shift, incumbents are often less productive in their research efforts than are new entrants (Henderson, 1993). What were considered core competencies during a period of incremental innovation can become "core rigidities" (Leonard-Barton, 1992), making it difficult for a firm to adapt. Years of incremental innovation may result in selection induced inertia, as only firms with stable structures and activities survive (Hannan & Freeman, 1977); such firms will find change difficult. Even if the core product technologies remain constant, changes in the way components interface can destroy the value of existing beliefs and patterns (Henderson and Clark, 1990). As a result, many have argued that competence-destroying technological discontinuities result in a turnover of industry leadership as incumbents are replaced by new entrants (Cooper & Schendel, 1976; Madumjar, 1984; Tushman and Anderson, 1986; Henderson and Clark, 1990).

2.2 Economic barriers to entry

The economic literature on barriers to entry argues that entry into an industry is determined by the estimated post-entry profitability of potential new entrants. Barriers to entry exist when incumbent firms are able to earn positive economic profits while making entry appear unprofitable to potential entrants. In making their calculations, potential entrants evaluate both the current status of the industry, as well as the anticipated post-entry behavior of incumbents. As a result, strategic behavior on the part of incumbents can influence entry decisions. In addition, once a new entrant is in the market, incumbents can often take predatory actions which decrease the likelihood of entrant success and encourage exit. I include such predatory behavior in my discussion of barriers to entry.

From the perspective of this literature, the success or failure of incumbents faced with a technological change depends upon how that change affects barriers to entry. If there are strong barriers to entry which remain intact following a technological shift, entry should be deterred and post-entry performance of new entrants should be poor. Likewise, when barriers to entry are destroyed by a technological shift one would expect higher levels of entry and better post-entry performance.

The innovation literature does not ignore barriers to entry; however, the implicit and sometimes explicit assumption of much of this literature is that destruction of current competence implies the destruction of barriers to entry. Tushman and Anderson state that "competence-enhancing discontinuities....increase barriers to entry and minimum scale requirements," while with competence-destroying discontinuities "barriers to entry are lowered" (pp. 445-446). I argue that the destruction of current competence does not necessarily imply the destruction of other of barriers to entry. By distinguishing between these two we gain a better understanding of incumbent survival.

For purposes of this analysis therefore, I classify barriers to entry as either based on current competence or not. I include as barriers based on current competence any barrier that depends upon the continued unique capability of an incumbent firm; if the capability were to go away, so would the barrier. Other barriers, alternatively, are independent of the current capabilities of the firm, although they can sometimes result from prior capabilities as discussed below. In the following sections I describe each type of barrier and the relationship between them.

2.2.1 Barriers based on current competence

Economists have developed formal theoretical models which demonstrate the deterrent value of the type of incumbent technological competence described in the innovation literature. These models assume that competence translates into a cost advantage either in manufacturing or product development.

Learning curve

In many cases, the cumulative experience of a firm in previous production runs lowers current production costs. The specific relationship between cumulative volume and cost is described by a learning curve. While economists have not emphasized the source of the cost decrease -- the internal organizational "learning" -- an implicit assumption is that this learning does take place. Organizations develop capabilities that enable them to lower costs. One can think about these capabilities as a current competence. As a firm produces more of a given product, both individuals in the organization and the organization itself "learn." Individuals become more proficient at performing specific tasks, and the manufacturing organization develops structures and procedures that make it more efficient. While some learning may be embodied in equipment, most is a tacit part of the organization, embedded in the types of communication patterns and routines discussed earlier. If for some reason all of the manufacturing employees had to be replaced at once with inexperienced workers, then costs would escalate, and the firm would have to go down the learning curve again.

If an incumbent can keep learning proprietary, then after a high enough cumulative production volume, a new entrant may be unable to duplicate the incumbent's cost position, and thus entry may be deterred. The investment in establishing a position on the learning curve can be thought of as a sunk capital cost. Once the incumbent has committed to that cost, a new entrant may not find it worthwhile to make a similar investment given the size of the market (Tirole, 1990). In addition, this advantage can be exploited through predatory pricing on the part of the established firm (Gilbert, 1989). By pricing low early-on in order to increase demand and accumulate experience, the incumbent establishes a low cost position quickly and preempts entry.

Innovative capability

The innovative capability that firms achieve within a particular generation of technology is analogous to the manufacturing experience which leads to cost advantages. If an incumbent can develop product innovations for a lower cost, then it can take advantage of this superior capability through predatory product innovation (Ordover and Willig, 1981). By introducing a product improvement and pricing it at slightly less than the amount that consumers are willing to pay for it, the incumbent can take over the market, leaving the rival with no sales and inducing exit.

2.2.2 Other barriers to entry

While the barriers to entry discussed above are dependent upon the current capabilities of the incumbent firm, others are independent of these capabilities. If current capabilities are destroyed or made obsolete, these other barriers may still be effective. I discuss four other types of barriers: economies of scale, sunk capital requirements, switching costs, and control over limited resources. I then discuss how, even though some of these barriers may result from historical competence, they can still be independent of current competence.

Economies of Scale

When economies of scale are significant, new entrants may be at a cost disadvantage relative to incumbents. For instance, if the minimum efficient plant scale is large relative to the size of the market, then, assuming it is rational for incumbents to maintain their pre-entry production volumes, a new entrant would have to enter at sub-optimal scale. The entrant would be at a cost disadvantage, and entry would be deterred. A firm's unique competence plays no role in how this relationship serves as a barrier.

While the structural relationship between optimal plant size and the size of the industry is important, the behavior of incumbents in exploiting that relationship is critical. For instance early work on limit pricing (Bain, 1956; Sylos-Labini, 1962; Modigliani, 1958) claimed that an incumbent could choose price and quantity such that the residual demand curve faced by the new entrant reflected a market price, at any feasible level of output, that would be below the entrant's average cost. Extensions to this work have shown that only under conditions of uncertainty about incumbent costs or the level of market demand will the limit pricing argument hold (Milgrom & Roberts, 1982).

Other extensions have explored ways in which incumbent firms can credibly commit to maintaining production levels. Dixit (1981) argues that irreversible capital expenditures, or "sunk" costs, can serve to commit an incumbent. These costs are sunk in that once made, they cannot be recouped. Sunk investments in capacity, for instance, lower the incumbent's marginal cost of production for levels of output below full capacity. The incumbent therefore has less incentive to decrease output in response to entry. For example, Ghemewat (1984) found empirical evidence of such strategic investments in the titanium dioxide industry.

Sunk capital requirements

If the capital necessary to enter an industry is a sunk cost, it has been shown theoretically to serve as a barrier to entry (Schmalensee, 1992). Since the potential investment contemplated by the new entrant cannot be recouped, and the incumbent has already committed to that investment, entry will only occur if the market is large enough to allow the entrant a return on its sunk investment.

Switching Costs

Switching costs can also serve as a barrier to entry. These costs arise when a customer incurs additional costs by purchasing a new entrant's product as opposed to an incumbent's product.

The reputation of incumbents is a switching cost in that customers must entail additional risk to try the product of a new entrant. This reputation can arise from many sources, including a history of customer service, product quality, and advertising. Once a reputation has been established, it is difficult for a new entrant to emulate it. Empirical work has shown that new entrants must advertise significantly more than incumbents in order to achieve the same level of effectiveness, putting them at a disadvantage. Incumbents firms can therefore act strategically by advertising early in an attempt to preempt new entrants (Tirole, 1990).

Other types of switching costs can be tied to the physical characteristics of the product. If a customer has invested in learning how to use an incumbent's product, then it will be costly to switch. Likewise, if a customer has made complementary investments, for instance in computer peripherals, which are only compatible with the incumbent's system, then there are substantial switching costs. Even if other firms have made their complementary components compatible, an incumbent with a dominant position in a base component, can make predatory changes to the interface with other components in order to eliminate competition. Assuming the new system offers superior performance, this move enables the incumbent to obtain at least a temporary monopoly position until other firms make their components compatible again (Greenstein, 1990).

Control over limited resources / patents

Unique access to limited resources can give incumbents an absolute cost advantage over new entrants in that entrants may have to pay inflated prices for factor inputs. Patent protection can also give incumbents a cost advantage since processes that lower costs may be protected from imitation. Once more, incumbents can engage in strategic behavior in order to take advantage of barriers such as patents. For instance, since an incumbent's market power allows it to extract greater benefits from incremental innovation than a new entrant might, incumbents have an incentive to invest more in incremental innovation and engage in preemptive patenting (Gilbert & Newberry, 1982).

Barriers arising from prior competence

Some of the "other barriers to entry" discussed above can be the result of the cumulation of competence over a period of time; they are a "crystallized" capability. These barriers can still be affected independently from current competence. For example, an important patent results from a firm's prior technological capability. I distinguish, however, between the patent itself, and the organizational knowledge which surrounds the patent since the two serve to deter entry independently. Once a patent has been granted, it has value to a firm distinct from the capabilities which led to the patent. If the firm were to suddenly lose that capability -- let's say the entire R&D organization moved to another firm -- then the patent would still serve as a barrier to entry despite the fact that the capability which led up to it was no longer in place. Similarly, once a patent expires and the structural barrier disappears, the capability which surrounded the patent can still serve as an entry barrier.

The importance of distinguishing between current capability and crystallized capability is especially important when considering the effect of technological change on barriers to entry. Whereas technological change may render the value of a current capability obsolete, it might not effect the crystallized capability. For instance, a reputation advantage may be the result of a history of high quality products. Even if the product development capability that led to the reputation were rendered obsolete by new technology, the reputation advantage might continue to exist with prior customers and would have some sort of decay function over time. If the new technology not only destroyed current competence, but also resulted in an entirely new set of customers, then the reputation advantage would also be destroyed since this new set of customers would not have the sunk cost of prior experience with the incumbent. Table 2.1 summarizes the classification of barriers as either based on current competence or other factors.

Table 2.1 Classification of Barriers to Entry

Barriers based on Current Competence	* Learning Curve * Innovative Capability
Other Barriers to Entry	* Economies of Scale / MES * Sunk capital requirements * Switching Costs - Reputation - Proprietary interfaces / compatibility * Control over limited resources / patents

2.3 Integrating current competence and other barriers to entry

Figure 2.1 contrasts the destruction of current competence with the destruction of other barriers to entry, giving examples from each cell. As discussed earlier, in much of the existing research on the failure of incumbents facing competence-destroying technological change, these two dimensions move in the same direction. For example, competence-destroying innovations identified by Tushman & Anderson (1986), such as the rotary kiln for cement, also destroyed other barriers to entry. At the other extreme incremental innovation, such technological change in the auto industry, has also had very little effect on other barriers to entry.

However, the impact of a technological shift on current competence and on other barriers to entry is not always the same. A technological shift may be incremental from the standpoint of competence, but have major effects on other barriers to entry. For example, the IBM PC standard was not technologically radical. Since it was an open standard as opposed to a proprietary standard, however, other barriers to entry decreased substantially. The customer switching costs of moving between vendors decreased since all vendors abided by the same standard. Since interfaces were open, it also became easier for new entrants to provide component parts. Whereas IBM had been accused of manipulating interfaces to deter component entrants in the mainframe business (Brock, 1975) it could not do so in the PC market.

Figure 2.1
Examples of the effect of technological innovation on barriers to entry

Current Competence Destroyed?	No	Yes
Yes	* Switching costs or reputation remain - IBM mainframes - CISC to RISC	* Rotary cement kiln
No	* Incremental innovation in the auto industry	* Movement from proprietary to open standard - IBM Personal Computer

Other Barriers to Entry Destroyed?

It is also possible for competence to be destroyed while other barriers to entry remain intact. For example, in the mainframe computer industry, IBM managed a great deal of radical technological change inside the mainframe 'box" without inviting entry. Since customers had invested significant amounts in developing products compatible with IBM's proprietary standards, the switching costs of moving to another vendor were substantial. By making its new products upwardly compatible with older versions, IBM was able to keep those switching costs high despite the technological shift. A new entrant's product would have to have been technologically superior enough to cover the customer's cost of switching vendors -- a situation which rarely arose.

In Figure 2.2 I describe the expected outcomes of being in different cells. I hypothesize that by explicitly considering both current competence and other barriers to entry, one can better understand the conditions under which incumbents survive seemingly competence-destroying innovations

Figure 2.2
Hypothesized position of incumbents vs. new entrants given technological change

Current Competence Destroyed? / Other Barriers to Entry Destroyed?	No	Yes
Yes	Incumbent survives, depending on relative magnitude	* Entry increases * New entrant performance advantage
No	* Entry deterred * Incumbent performance advantage	New entrant succeeds, depending on relative magnitude

Hypotheses regarding the amount of entry and the performance of new entrants under different conditions can thus be summarized by the following relationships:

$$E_{ee} < E_{ed} \; ? \; E_{de} < E_{dd}$$

where E stands for the amount of new entry, the first subscript represents the effect of a technological shift on current competence and the second the effect on other barriers to entry. If the subscript equals e, the barrier is enhanced and if it equals d, the barrier is destroyed. The same factors which influence a potential entrant's entry decision also influence the market share a firm will achieve once it enters (Geroski, 1991), so the hypotheses related to market share are the same as those related to entry.

Clearly in situations when a technological shift does not destroy either current competence or other barriers to entry, one would expect entry to be difficult, and if firms did enter, incumbents would still have an advantage. Likewise, when both types of barriers to entry are destroyed, then entry should be feasible, and new entrants should be more successful at entering and penetrating the market.

The importance of distinguishing between current competence and other barriers becomes clear, however, when these effects work in opposite directions. In these cases the outcome depends upon the relative strength of the two effects. We may therefore encounter "unexpected" results if only a single perspective is considered. For instance, if current competence is destroyed, while other barriers remain, it is possible that the other barriers can serve as a buffer, allowing an incumbent to develop technological capability at a slower rate than potential new entrants. Incumbent firms might therefore perform well despite undergoing competence-destroying technological shifts. At a minimum, one would expect that incumbents facing competence-destroying shifts would fare better when other barriers to entry retain their value, than when they do not. In that sense, by only examining the effect of a technological shift on competence, we are missing a critical element, and may have incorrect expectations.

In the reverse case, when current competence is not destroyed yet a technological shift destroys other barriers to entry, one might find that seemingly minor innovations from a competence-based standpoint have dire competitive consequences for incumbents due to shifting structural dynamics. Again, by examining only competence, we are only capturing part of the story.

2.4 Alternative explanations for incumbent survival

This framework is also useful in that it helps to synthesize other findings regarding the survival of incumbents faced with competence-destroying technological change. One can think about many of the explanatory factors described in other empirical work in terms of barriers to entry. Afuah (1994) proposes that by making an innovation less competence-destroying for other members of the value chain, (i.e. suppliers, customers and complementary producers) incumbents can be more successful. Maintaining upward compatibility in the competence-destroying shift from CISC to RISC processors was found to have a significant effect on incumbent success. Another way to think about upward compatibility is in terms of switching costs. In some sense, the CISC/RISC story is similar to that of IBM in the mainframe computer market described earlier. Once a customer has invested in learning to be efficient using the vendor's current CISC product, switching to another vendor incurs a cost. If the incumbent can keep the customer's investment in learning its CISC product valuable despite a technological shift to RISC, then it can maintain the switching cost of changing vendors as a barrier to entry. Even if the incumbent's product is technologically inferior, as long as the cost of changing vendors is greater than the penalty from purchasing an inferior product, the customer will continue to buy from the incumbent.

Mitchell (1992) finds in the medical diagnostic imaging market that if a technological shift is not radical from a market perspective then incumbents have a higher likelihood of surviving technologically radical change. This finding can also be thought of in terms of barriers to entry. The factors that remain constant when a shift is incremental from a market perspective can be exploited as barriers to entry. For instance, control over limited distribution channels, as long as those channels remain constant, can deter entry. Similarly, if the set of customers remains the same, then a firm's reputation in the market maintains its value and can serve as a barrier to entry.

Finally, Rosenbloom and Christensen (1994) find that if the value network remains constant, then incumbents are more likely to do well. When the value network remains the same, firms are serving the same set of customers with the same set of needs through the same set of channels. In this situation, factors such as reputation and limited access to distribution can serve as barriers to entry and allow incumbents to be successful despite being technologically inefficient.

2.5 Summary

This chapter has presented a framework which highlights the importance of considering the effect of a technological shift on both current competence and other barriers to entry. To test the impact of destroying either current competence or other barriers we therefore need to control for both effects. By testing for the effect of competence-destruction alone, for instance, we may reject the hypothesis that competence-destruction puts incumbents at a disadvantage, when in fact it is the effect of other barriers to entry we are observing. An appropriate research setting to test for these effects, therefore, should include observations that destroy competence but not other barriers to entry and vice versa. The next chapter describes such a setting: the typesetter industry.

Chapter Three

Research Methods and Data

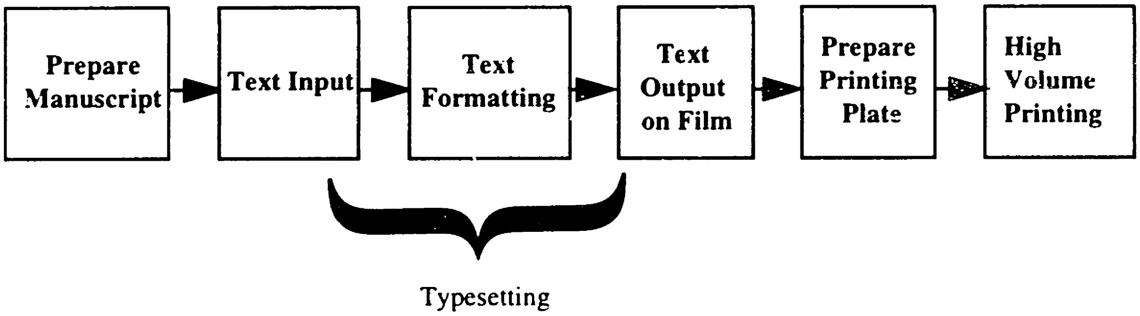
This chapter describes the methods and data used to address the issues raised in Chapter Two. I first discuss the research setting, the typesetter industry, briefly reviewing what a typesetter is and why the industry provides an appropriate vehicle for exploring these issues. I then describe the processes used to gather the necessary data about the industry. Finally, I review the specific methods used to analyze the data. Quantitative analysis of industry-level patterns is combined with case studies of a subset of firms in the industry.

3.1 Research setting: the typesetter industry

Typesetting is the process of arranging and outputting text (and now images) as an input to high quality and/or high volume printing. A typesetter machine automates this process. A typesetter originally performed three basic steps: text input, text formatting, and text output (see Figure 3.1). Text was input from a prepared manuscript, usually via a typewriter-like keyboard. The text was then formatted either manually by the operator of the typesetter, or automatically. The formatted input was then used to create output appropriate for interfacing with a printer.

Figure 3.1

The Typesetting Process



Over time advances in technology have resulted in a number of changes in the functions that the typesetter performs. Whereas early typesetters produced metal output with raised letters for use in letterpress printing, later machines produced film output for use with offset lithographic printers. With increased computerization, the formatting of text is now often done by a separate "front end system," and the typesetter is responsible for producing the formatted output on film. Finally, the integration of text and images on a page has resulted in typesetters becoming imagesetters. Buyers of typesetters include newspapers, typographers, commercial printers, in-plant and book publishers and service bureaus.

The typesetter industry provides an ideal setting for examining the survival of incumbent firms faced with competence-destroying technological change. Despite multiple technological revolutions, with entry and exit at each stage, some of the firms established in the late 1800s are still present in the industry today. The industry thus provides an opportunity to understand both what drives overall industry patterns of incumbent and entrant performance as well as what drives the performance of superior firms.

Since its inception in the late 1800s, the typesetter industry has experienced five generations of technology: 1) hot metal, 2) analog phototypesetters, 3) digital CRT phototypesetters, 4) digital laser imagesetters, and 5) digital Postscript laser imagesetters. If one classifies these generations according to the 2x2 matrix in Chapter Two (Figure 2.2), one finds examples from each quadrant. This enables an analysis of the effects of competence-destruction as distinct from the effects of destroying other barriers to entry.

Although the industry might initially sound "low-tech," it has undergone significant technological change, and firms have invested substantial amounts in R&D. From 1985 to 1990 industry R&D as a percent of sales averaged 10%. Patent protection and the ability to "invent around" existing patents are also important, and a number of significant patent suits have emerged in the industry's history.

Analysis of how technological change affects both industry entry/exit patterns and market share are facilitated by a great deal of variation in these factors over time. Between 1886 and 1993, 68 different firms participated in the industry at some point. The maximum number of firms in the industry was 25 and the minimum 3. Market share has also varied significantly. Firms which accounted for 100% of the hot metal generation accounted for only 11% of machines sold in the analog phototypesetter generation. Despite a great deal of entry and shifting market share, some firms, specifically Mergenthaler Linotype (now Linotype-Hell) and Compugraphic (now Agfa-Compugraphic), have consistently outperformed the industry. By examining these firms in depth and comparing them to other firms, one can gain some insights into the how a firms develops new technological capabilities.

Finally, the industry had multinational competitors with different country home bases from very early on. This provides an opportunity to examine the effect of different country institutional environments on firm performance.

There are clearly trade-offs involved in studying a single industry in-depth as opposed to performing a broad cross-sectional study across multiple industries. For the purposes of this research, the benefits of a single-industry study outweigh the disadvantages. While there is no single "correct" definition of an industry, the quality of data available for cross-sectional work often forces one to a relatively high level of aggregation. For instance, many publicly available statistics are only kept at the 4-digit SIC code level. While appropriate for some work, this level of aggregation is much too high to address the types of issues raised in this study. Multiple industries with very different economics -- different manufacturing processes, different competitors and different buyers, for instance -- will often be grouped under a single heading. Typesetter machines are part of SIC 3555, Printing Trades Machinery, a category which also includes printing presses and binding machinery and equipment. Very few firms participate in all three of these segments. In addition, the technology needed to design and manufacture these different machines is quite varied. Examining the effects of technological change on entry into the "industry" or on market share at the Printing Trades Machinery level of aggregation therefore has little meaning.

In addition, in order to evaluate the effect of different technological generations on an industry, it is critical to have a detailed understanding of the relevant technologies. That understanding includes, for instance, measures of technological performance, descriptions of the skills required to develop products within each generation, and descriptions of the underlying product architecture. These factors must all be tracked over time. Without a longitudinal perspective, one loses any understanding of industry dynamics. In the typesetter industry, this means tracking over 100 years of industry history. The need for longitudinal data covering detailed technological changes in a narrowly defined industry makes an in-depth single industry study the only feasible alternative. Obtaining data of this quality requires intensive and time-consuming field work. It is simply not feasible to perform that type of work across a large cross section of industries.

The obvious concern with this approach is the inability to generalize results. The concepts developed here, however, can certainly help one to think systematically about other industries and how they evolve. In addition, while industry studies in isolation may not prove generalizable, when combined with other industry studies, patterns begin to emerge. One would hope that this dissertation, in combination with other in-depth industry studies (e.g. Henderson, 1993, Christensen, 1993; Utterback, 1994) begins to shed more light on the relationship between technological change and industry / firm evolution.

3.2 Data and Sources

Data for this research was collected during a 18-month field-based study of the industry conducted from the fall of 1993 through the winter of 1995. The core of the data consists of a comprehensive longitudinal dataset covering the entire history of the worldwide industry from 1886, when the first successful mechanical typesetter, the hot metal Linotype machine, was introduced, through 1993. The dataset includes the entry date of every firm in the industry and for those firms that exited, the exit date. Detailed product-level data for almost every product introduced by these firms was also gathered. These data include product performance characteristics, price, and unit sales over time. Firm-level data are supplemented by industry-level data, including industry size and growth, and plant sizes. Finally, for four case study firms, data on factors such as the internal organization structure, the composition of product development teams and the resource allocation process were collected. These data come from a combination of primary and secondary sources listed in Table 3.1.

Table 3.1 Sources

Primary Sources	**Examples**
Interviews	* Current and Former Employees - Mergenthaler Linotype, Monotype, Photon, Compugraphic, Varityper * Users - Newspapers, Commercial Printers * Industry Experts
Personal archives	* Current and Former Employees - Product development plans, Organization charts, Personal memos
Firm archives	* Linotype-Hell and Agfa Compugraphic - Company newsletters, Organization charts, Strategic plans, Sales manuals, Product literature
Conferences	* Seybold Conference on Publishing Systems
Secondary Sources	**Examples**
Technical journals, and conference proceedings	* Journal of Typographic Research, * Dunn Conference on Electronic Publishing
Technical books	* *The World of Digital Typesetting,* J. Seybold * *A Concise Chronology of Typesetting Developments: 1886 - 1986,* L.W. Wallis
Historical books	* *History of Composing Machines*, Thompson (1904) * *Typographical Printing Surfaces: The Technology and Mechanism of their Production*, Legros and Grant (1916)
Trade journals	* Seybold Report * CIS Newsletter * Publish * Graphic Arts Monthly * British Printer
Consultant Reports	* Datek * Datapro * Arthur D. Little * State Street Consultants
Industry Association and Government Reports	* Graphic Arts Technical Foundation * NPES Association for Suppliers of Printing and Publishing Technologies * Graphic Arts Marketing Information Association * ANPA (American Newspaper Publishers Association) * Census of Manufacturers
Company Publications	* Annual Reports * Product promotional literature

3.2.1 Primary field research

Interviews

In-person and phone interviews provided the richest source of qualitative data on the industry and on specific firms. In total, over 50 interviews were conducted, with the interviews lasting from 2 hours to all day. Appendix A provides a list of individuals interviewed. Interviewees were mailed or faxed a list of questions before the interview. Appendix B provides a sample of interview guides used. About half of the interviews were in-person, with the remainder conducted over the phone. Most in-person interviews were tape recorded and transcribed.

Interviewees fell into two broad categories: 1) those currently or formerly employed in the industry, and 2) industry historians and "experts." For Mergenthaler Linotype and Compugraphic, the two firms studied in the most depth, my goal was to interview a sample of individuals who had a) been with the firms at different points in their evolution, b) had experience in different functional areas and c) were at different levels in the organization. Since I was interested in technological transitions, clearly I wanted to speak with development engineers and engineering managers, but I also felt it was important to speak with individuals who had been in marketing as well as upper level management. As one can imagine, the task of finding and contacting individuals with appropriate experience for 60 years of Mergenthaler's history and 30 years of Compugraphic's history was a bit daunting.

The process of finding relevant individuals differed for the two firms and involved a combination of serendipity and persistence. For Mergenthaler Linotype, since the US and UK development organizations had been closed down and only the German organization remained, I was faced with the task of tracking down ex-employees if I wanted to understand what went on inside the firm during critical transitions. In addition, in order to understand the initial transition from hot metal to analog phototypesetting, I needed to find retired employees who had worked at the firm in the early 1950s.

Luckily, I obtained initial contact, through a colleague, with Matthew Carter, a type designer who lives in Cambridge, MA. Not only had Matthew Carter worked at Mergenthaler Linotype as a type designer during the hot metal era; he had also worked at Crossfield Electronics, a British firm in the industry, Bitstream, a digital type design firm, and currently has his own type design firm. In addition, his father had been a well known printer in the UK. Matthew was therefore very well connected, and he was able to give me the names and numbers of multiple ex-Mergenthaler employees. From that point onward, my network of contacts multiplied as each interviewee pulled out his Christmas card list and gave me the phone numbers of people he had worked with in "the good old days." In the end, I was therefore able to interview staff engineers, engineering managers and marketing/sales personnel present during each generation of technology. I was also lucky enough to meet with senior management including Jack Keller, the CEO of Mergenthaler during its initial transition to analog phototypesetting, and Derek Kyte, the technical director of the UK company, K.S. Paul, bought by Mergenthaler in 1968.

Finding Compugraphic employees was much easier in that the firm is much younger than Mergenthaler and it is still based in the Boston area. By calling the firm, I was able to meet with Dick Renwick, vice president of manufacturing and one of the original ten employees of the company. He was able to provide me references to relevant current and former employees. Once more I was able to interview staff engineers, engineering managers marketing/sales personnel and senior managers.

In addition to personnel from Mergenthaler and Compugraphic, I also interviewed numerous ex-employees of Monotype, Intertype, Photon and AM Varityper as well as a number of industry consultants.

The goal of my interviews was to 1) obtain general information about changing typesetter technology and 2) understand how Mergenthaler and Compugraphic had successfully made the transitions between generations of technology while other firms had failed. As can be seen in Appendix B, I asked for information about items ranging from how different generations of technology worked to how the organization was structured. Although a detailed study of product development processes was precluded, given how long ago many of these products were developed, I at least wanted to get an overall sense as to how product development worked. Did the engineers communicate with sales and/or marketing? How much did they rely on suppliers and other outsiders for information? Were all development teams housed in the same location? How large were the teams? The ability of individuals to recall specific product development efforts was frankly quite impressive.

Industry experts were most helpful in providing background on the 68 firms that participated in the industry over time, and in confirming information that I had heard in other interviews. Printing historians were especially helpful in tracking down entry and exit information about firms from the 19th century.

Archives

Personal: Often, retired employees had saved substantial amounts of material related to their former companies. While much of this material was personal in nature -- e.g. patent awards or performance reviews -- much of it was quite useful. For example, one individual had saved almost every promotion memo at Mergenthaler Linotype from 1950 to 1980! This information helped to identify the background and skills of both engineering management and firm management. Many historical organization charts were also available from personal archives, and these helped in identifying the necessary skills for product development in each generation of technology. Specific product information such as performance characteristics and sales figures were also found. For example, while Linotype-Hell had no firm archives with specific unit sales figures on phototypesetter models, one retired individual had saved memos that chronicled the sales of multiple models.

Firm: Firm archives were examined at Linotype-Hell and Agfa-Compugraphic. At Linotype-Hell, internal company newsletters going back to the 1920's provided data on the internal organization structure as well as the company culture over time. Hand-written records provided the shipping date and customer for every hot metal Linotype machine sold in the US from 1890 though 1930. Old sales manuals included data on product features and prices, including some competitive data. In addition, old strategic plans provided internal sales data as well as competitive data on the market. Similar information was available at Agfa-Compugraphic. Strategic plans and consultant reports done for the firm contained information about the firm's strategic direction as well as market share and sales data for the industry as a whole.

Industry Conferences

Twice a year, a major industry conference, the Seybold Conference on Publishing is held. I attended this conference twice. While the focus is on current developments, a wealth of individuals with a long history in the industry are present at the conference. In addition, firms often had documents that reviewed their history. This data was especially helpful in tracing the background of new entrants.

3.2.2 Secondary Data

Primary research was supplemented by extensive reading about the industry from secondary sources. A complete listing of secondary sources is included in the technical bibliography.

Technical books and journals

To understand the specifics of technological change in the industry, I read a number of technical books about the industry. These books contained technical specifications and performance details about products from every generation of technology.

Trade journals

The single most valuable source of information for this study was the Seybold Report, an industry journal. Started in 1971, the Seybold Report reported on every entry into the typesetter industry as well as every major new product announcement. Technical product evaluations were provided, including a discussion of product specifications. Until recently, each year, a chart was compiled that listed almost all products available in the industry, product characteristics and product prices. Occasionally product sales data were also reported. Other journals were used to supplement and cross check information from the Seybold Report.

Consultant, Industry Association and Government Reports

An industry consultant, Frank Romano formerly of Datek Information Services, provided much of the basic data on product sales over time, with numbers on cumulative sales through 1975 and annual sales for 1976 through 1984. These data were supplemented by and cross checked with data from Dynamic Strategies Incorporated and State Street Consultants. All numbers were also cross checked with industry association reports, government reports, trade journals, internal archival data, and industry experts.

3.3 Overview of methods

I began my analysis with an in depth study of the technologies in the industry in order to understand how different technologies affected both firm capabilities and industry structural factors. I then used a combination of quantitative modeling and case-based research methods to explore the issues raised in Chapter Two. Models are used to explore the effect of technological change on entry rates and on the relative position of incumbents vs. new entrants. The quantitative work thus tests the hypotheses relating to entry and market share in Chapter Two. This work is supplemented by detailed case studies of Mergenthaler Linotype and Compugraphic, and briefer studies of Monotype and Intertype. These case studies examine the development of dynamic capabilities and help to improve our understanding of how firms can best develop new technological capability.

3.3.1 Detailed study of the technology

The goal of this part of the research was to understand the nature of technological change in the industry. I wanted to have a very clear sense of how typesetter technology changed over time and how those changes affected the capabilities of firms in the industry as well as structural barriers to entry. The classification of technological generations as "competence destroying" and "other barrier destroying" is based on this analysis. Detailed schematics of products from each generation were examined in order to understand the basic product architecture. As discussed above, this material was available in technical books and journals. Interviews with product developers and an examination of archival materials allowed a determination of the skill set required to develop each generation of technology.

3.3.2 Quantitative analysis of industry evolution

The quantitative analysis comprises two parts. I first analyze industry entry patterns by technological generation using a Poisson model of entry counts. This analysis gives me a sense of how the destruction of current competence and other barriers affects the number of entry attempts. In order to understand whether entrants were successful, I supplement this analysis with an examination of the determinants of product market share.

3.3.3 Firm case studies

While the quantitative analysis focuses on differences between incumbents and new entrants, the qualitative case studies shed light on differences in performance among incumbents. Two highly successful firms across multiple generations of technology, Mergenthaler Linotype and Compugraphic, are studied in depth, and two less successful firms, Monotype and Intertype are studied more briefly. These firms were chosen in that they provide an excellent forum for comparison. Mergenthaler was the original hot metal firm in the industry and is the only hot metal firm to have survived and prospered given the substantial technological change in the industry. By comparing Mergenthaler with Monotype and Intertype, the two other hot metal competitors, I gain insight into what made Mergenthaler successful. As the most successful new entrant to the industry, Compugraphic provides an interesting contrast to Mergenthaler in terms of examining how each firm survived subsequent changes in technology given its background.

Chapter Four

Technological Change in The Typesetter Industry

4.1 Introduction

This chapter describes the evolution of typesetter technology from 1440 through 1990. It traces the origins of each major generation of technology and analyzes the factors that influenced technological change. Three main themes emerge from this story.

First, radically new technology often originates outside the industry and is introduced by new entrants. Basic advances in electronics, for instance, did not originate within the typesetter industry, and incumbent typesetter manufacturers were slow to recognize and incorporate these advances. New entrants took advantage of the new technology and introduced the first electronic typesetters.

Second, consistent with prior work (von Hippel, 1988), users were responsible for significant innovation. Typesetter users were among the first to develop second and third generation machines. In addition, user financing of innovation was also important, with users funding both the original automation of typesetting as well as the second generation of technology.

Third, shifting demand conditions in the form of new user needs had a major influence on the direction of technical change. These needs originated both from the emergence of new segments and from the changing needs of existing segments. For instance, as the market for typesetting services expanded to include magazines in addition to newspapers, the need to incorporate pictures with text influenced typesetting technology. The needs of existing segments changed in response to new technology at other points in the printing value system. Due to system interdependencies, other products often imposed demands on typesetters. For instance, the shift from letterpress to offset lithographic printing meant that the typesetter needed to produce a film input as opposed to a metal one. Similarly, as the graphics capabilities of front end systems evolved, the ability to output text and graphics simultaneously was required of typesetters.

I begin by describing the origins of the typesetter industry and initial attempts to automate it. The first successful attempt was the hot metal Linotype machine invented by Ottmar Mergenthaler in 1886. I describe the technology embodied in this machine and how it rose to prominence. I then examine each of the four following generations of technology, analyzing the context in which the technology evolved and describing the technology and the characteristics of the firms initiating change.

4.2 The origins of the typesetter market

4.2.1 Gutenberg and moveable type

Typesetting originated with the invention of moveable type by Johann Gutenberg in about 1440. Prior to Gutenberg's invention, written material was available to only a small, elite portion of the population. Moveable type, however, enabled significantly larger quantities of printed material to be produced. The printing and newspaper industries emerged, and along with them, the craft of typesetting. Highly skilled individuals called compositors were trained to "set" individual pieces of moveable type - pieces of metal with raised letters - in preparation for printing. Working from a handwritten manuscript, these individual took pieces of type from two cases -- an upper case containing capital letters and a lower case containing small letters -- and placed them in the correct order on a composing stick. Once a line was ready, it was placed in a page-sized form to be printed. When a complete page was ready, the form was locked tightly so that the type wouldn't move. It was then "inked" and paper pressed against the raised letters to create a printed page. After the desired number of copies were printed, the type was manually redistributed to the cases.

The individual pieces of type used in hand typesetting were called foundry type and were generally designed and manufactured by specialized type foundries. These firms cast hot metal into individual molds of letters in order to produce pieces of type. Given the frequency with which these pieces of type wore out, there was continual demand, and most large cities had their own local type foundry.

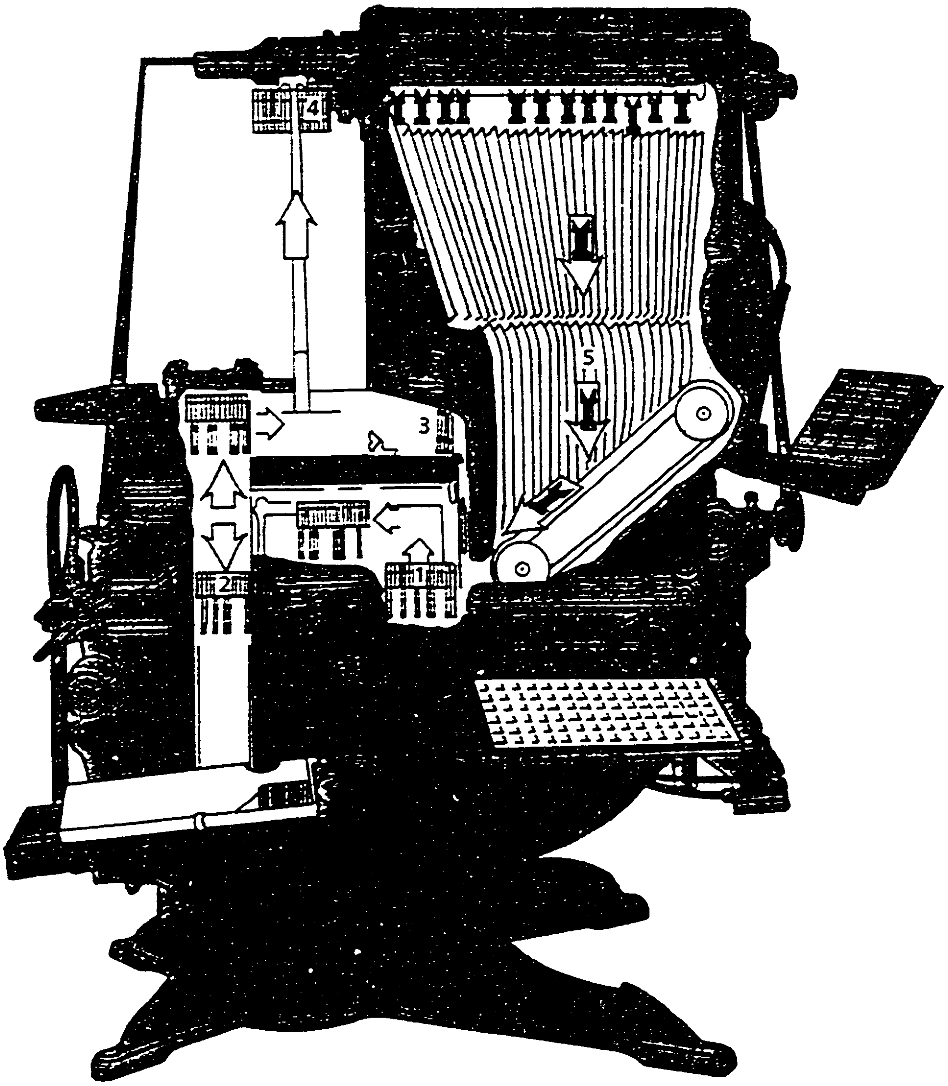
4.2.2 The invention of the Linotype machine

As larger portions of the population became literate, the demand for printed material rapidly escalated. A desire to speed up the process of typesetting was natural, and several inventors confronted this challenge. The most successful of these was Ottmar Mergenthaler with the Linotype machine. The following quotation from the Mergenthaler Linotype Company's *Linotype Machine Principles* summarizes the operation of the "linecaster." (see fig 4.1).

> The Linotype is not a typesetting machine. No types are used in it. It composes with matrices - small brass units having characters indented in the edges - hence the name "matrix." These matrices are assembled into justified lines. From the matrix line the Linotype automatically casts a solid bar, or line, of type. This bar is known as the Linotype slug. It is ready for use when it leaves the machine. The Linotype has four major divisions:
> **1. The Magazines which contain the matrices.** They represent type cases. Because every matrix circulates automatically back to its place in the magazine as soon as it has served in a line of composition, a font of matrices is small in number as compared with a font of type. A magazine is so compact and light that the operator can handle it without exertion, and produce a variety of composition simply by changing magazines.
>
> **2. The Keyboard and its related parts.** This controls the release of matrices from the magazine in the order in which the characters are desired. The Linotype operator, from his seat at the keyboard, has complete control of every function of the machine. His duties are limited merely to operating the keyboard keys - justification and distribution are mechanically automatic.

Figure 4.1

Operation of the Hot Metal Linotype Linecaster



"Lines of matrices and spacebands are collected in the assembly area (1) and then are transferred to the casting area (2). After the slugs have been cast and delivered to the galley in the front of the linecaster, the matrices and spacebands are redistributed: spacebands at the upper left (3) and matrices in the magazine (4). Each matrix occupies its own channel within the magazine and descends to the assembly area when the character's key has been struck (5) " (Seybold, 1984, p.44)

> **3. The Casting Mechanism.** The division of the machine makes the Linotype-equipped printer his own type founder. The justified line of matrices is presented automatically to the casting mechanism, molten type metal is forced into the indented characters on the edges of the matrices, and the cast line, a single unit with a new typeface, is delivered to galley on the machine, precisely trimmed and ready to go into the form.
>
> **4. The Distributing Mechanism.** When a line of matrices has served for casting the line of type, it is lifted automatically and carried to the top of the magazines, where, by a simple though ingenious system, each matrix is delivered to its proper place in the magazine and is ready to serve again. Thus, in the Linotype-equipped shop, there is no distribution of type.

As in many industries, (von Hippel, 1988) users, in this case newspapers, had critical influence on the development of the technology. The desire to speed up the typesetting process and extend news deadlines, combined with the expense of hand typesetting, gave newspapers a strong incentive to invest in automation. As a result, a syndicate of newspapers funded the commercial development of the Linotype machine through the establishment of the Mergenthaler Printing Company in 1886. They also provided early user feedback on the machine by serving as a testing ground: the first Linotype machine was installed at the *New York Tribune* in 1886. Based of this feedback additional improvements to the machine were made, and the first true production model, the Square Base Linotype was demonstrated in 1890.

The Linotype machine was superior to hand typesetting in many ways. It was much faster, setting type at about 6000 letters per hour as compared to 2000. In addition, rather than a compositor putting individual pieces of type back into cases by hand, matrices were automatically redistributed, saving a great deal of time. Finally, the inventory investment in type was significantly reduced since matrices were reusable once a line was cast.[1] Mergenthaler sales literature from 1895 quotes a customer from the *New York Recorder* comparing "then" and "now"

> THEN - (Hand Composition)
> Seventy-two compositors. $2800 weekly payroll, 50 cents a thousand for composition, no end of trouble
>
> NOW - (Linotype Composition)
> Fifteen compositors, 23 machine operators, set 50 % more matter, $1600 pay-roll, 18 cents per thousand composition, smooth sailing.

4.2.3 Early competition and shakeout

While clearly superior to hand typesetting, the Linotype machine did not have an unchallenged ascendancy in the automated typesetter market. There was a period of ferment during which multiple competing designs vied for dominance. As in many cases (Utterback, 1994; Klepper & Graddy, 1990), the industry experienced a great deal of entry and eventually a shakeout as the Linotype "linecaster" architecture became dominant. Figure 4.2 shows the number of firms in the industry from 1869 through 1955, and figure 4.3 shows how market share is distributed at select points. Note that firms continue to enter the industry until it reaches a peak in 1897. At about this time, sales of Linotype-architecture machines make up more than half of industry sales.

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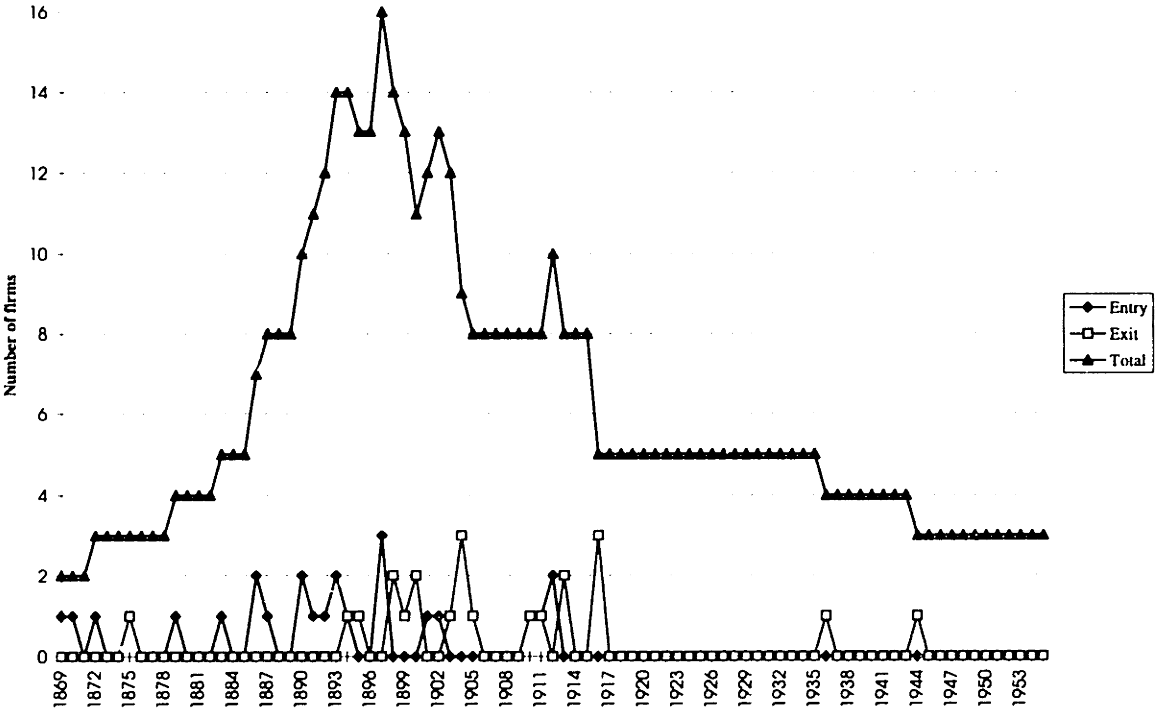
[1] In some sense the Linotype machine was competence-destroying for the firms that manufactured metal type. As the demand for moveable type diminished, these firms were face with a need to adjust. In 1892, as a defensive move in response to the increased acceptance of Linotype machines, 23 of the 28 type foundries in the US merged to form the American Type Foundry (ATF).

Figure 4.2

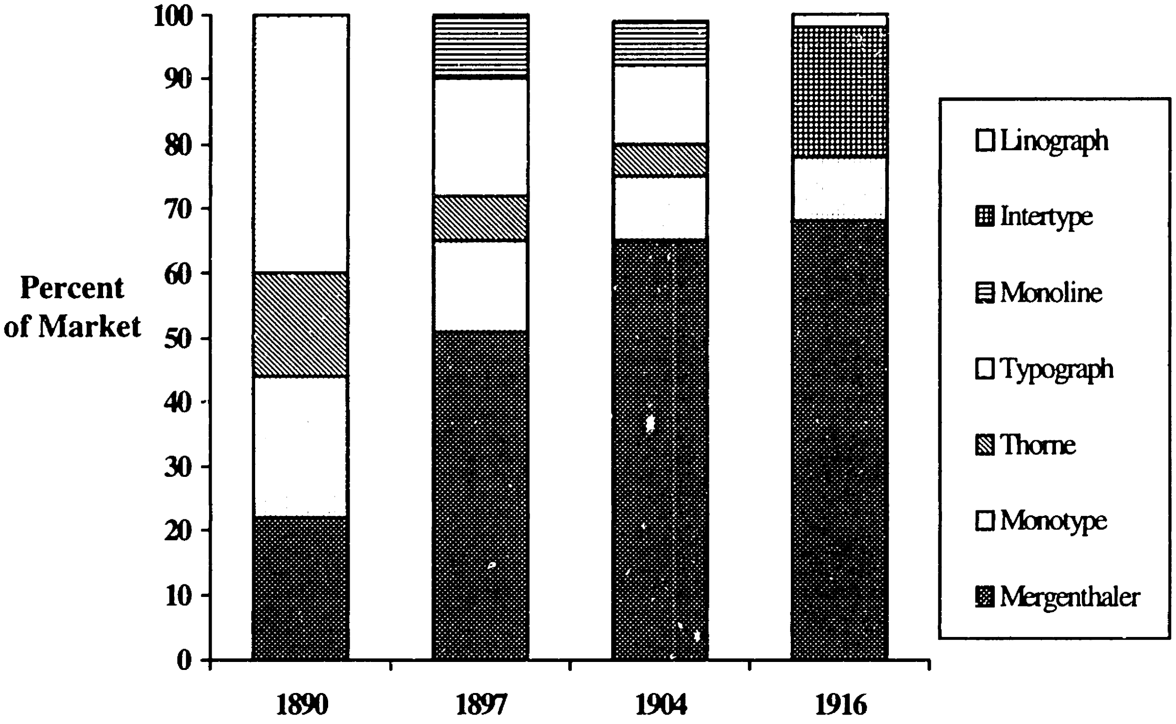
Number of firms in the typesetter industry, 1869 - 1955



Source: Thompson, 1904; Legros & Grant, 1916; Huss, 1973; author's analysis

Figure 4.3

Typesetter Market Concentration, 1890 - 1916



Source: Author's Analysis

I next describe some of the main competitors during the period of ferment and how the Linotype machine dominated in the subsequent shakeout. Although the Linotype machine was technically superior to most of the competition, it took aggressive enforcement of patent rights, direct price competition, and multiple acquisitions[2], for Mergenthaler to drive most of these firms from the market.

Foundry type machines

When the Square Base Linotype was announced in 1890, about 200 to 300 typesetters of varying designs were in use in newspapers and printing shops (Goble, 1984). Most early typesetter inventors attempted to automate the existing process of setting type by hand. Figure 4.4 shows a cartoon from the *American Printer* which characterizes the mindset of these inventors. The first operative machine of this type was patented in 1822 by Dr. William Church of Boston, MA, although it was never commercialized. From that point on over one hundred "foundry type machines," which re-circulated pre-cast type, were patented, but few physical models were actually constructed (Thompson, 1904). The fragility of the individual pieces of type caused problems. As one contemporary review (Southward, 1890) noted,

> "Some of them cause a great deal of damage to the type. Unless they are well designed, perfectly adjusted, kept in a proper state of repair and worked by careful, experienced and loyal operators, they may break a considerable weight of type... Even if the type is not broken, it may be worn unduly. The edges are often rounded by frequent passage through the channels and the guide-plate grooves."

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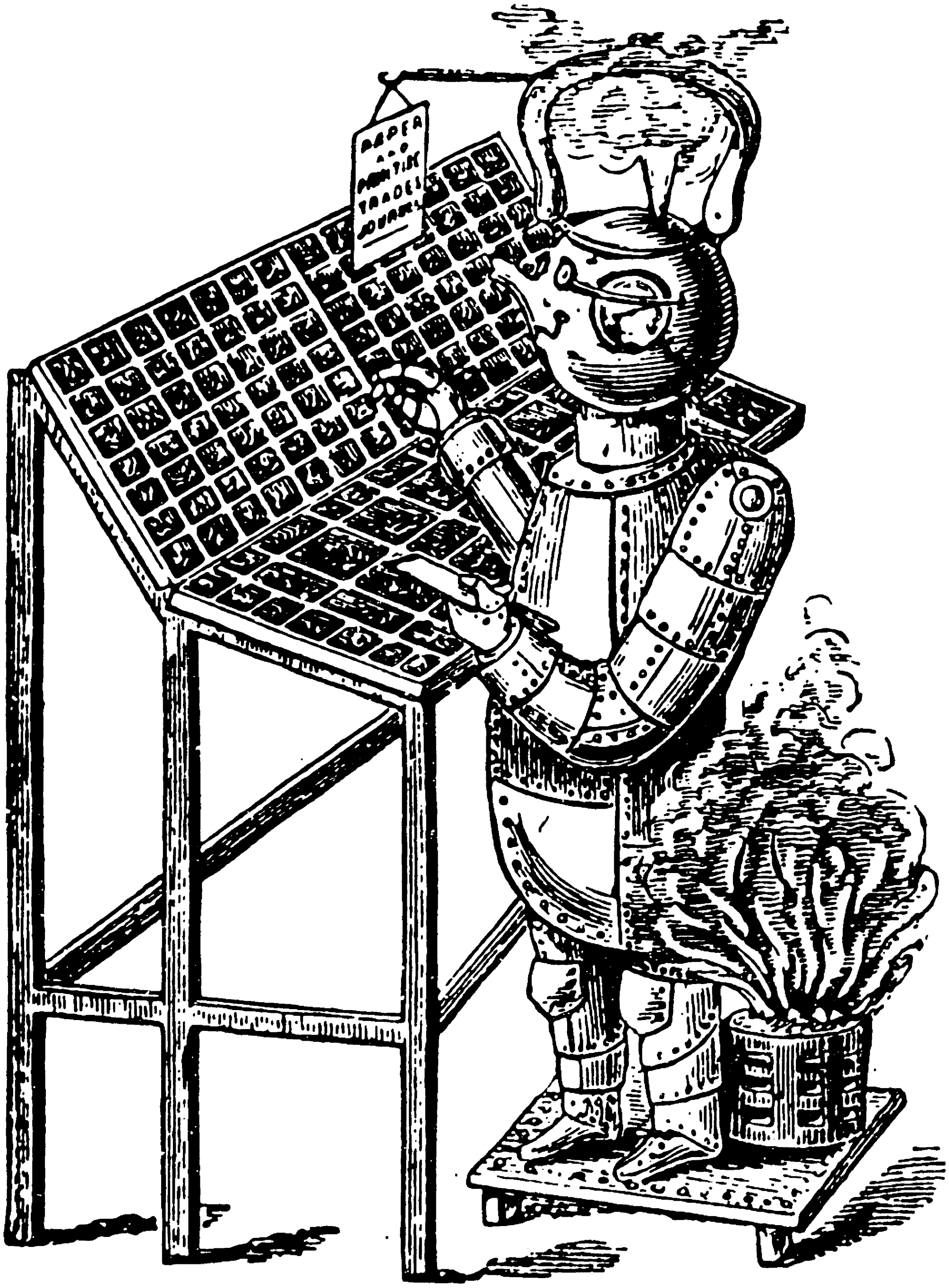
[2] Despite the firm's dominance, none of Mergenthaler's acquisitions was ever challenged on grounds of antitrust.

Figure 4.4

Early Perspectives on Automated Typesetting



Source: *American Printer*, February, 1912

Despite the technical disadvantages, a few foundry type machines, the Thorne (figure 4.5), the Burr-Empire (figure 4.6), and the Paige (figure 4.7) typesetters, experienced moderate commercial success.

Thorne

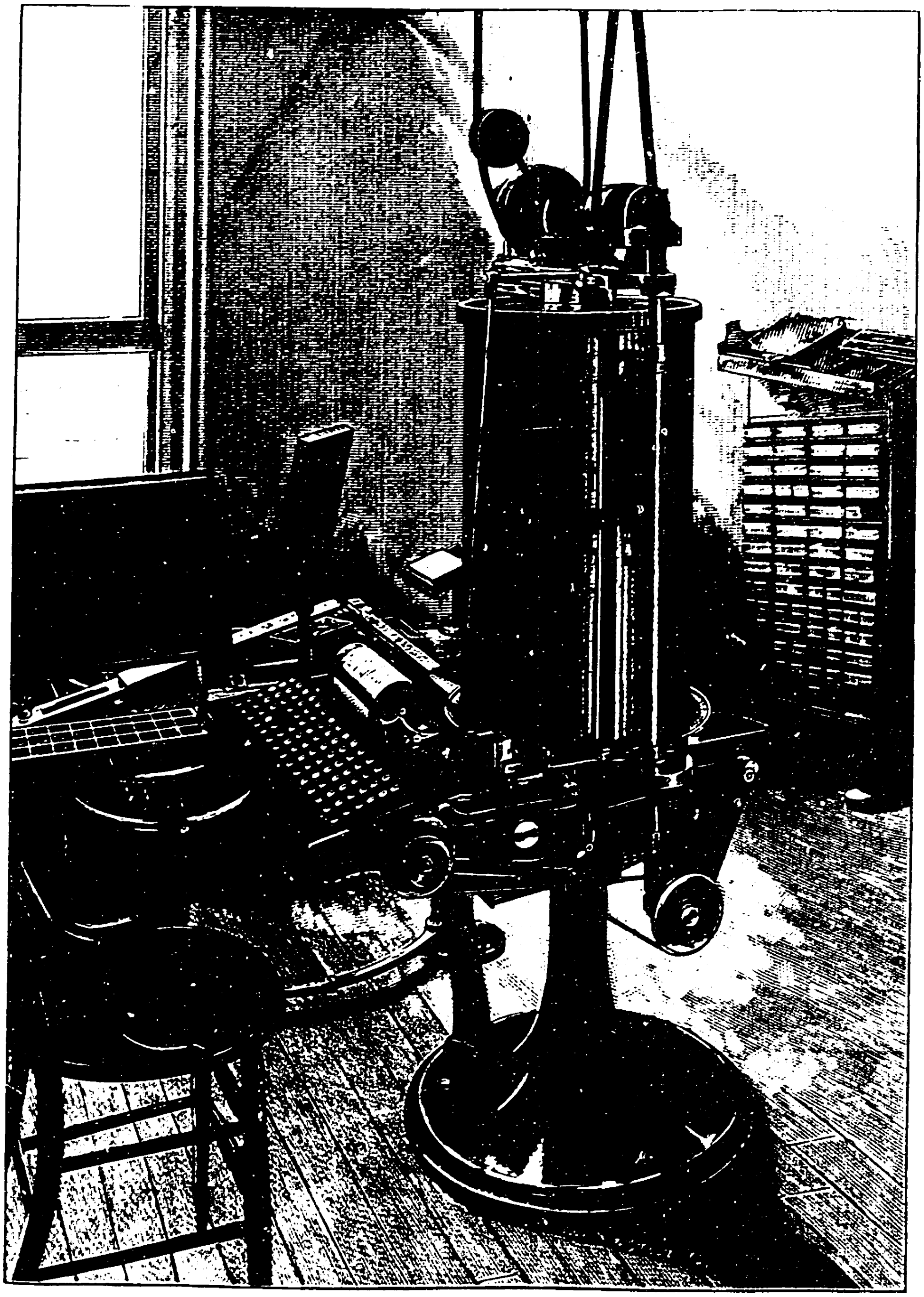
The most successful foundry type machine was the Thorne typesetter (later renamed Simplex and then Unitype). This machine was patented in 1880, although the first one wasn't installed until 1886. Approximately 1500 machines were sold by 1903. Priced below the Linotype, and with greater technical reliability than other foundry type machines, the Thorne was a serious competitor. Mergenthaler therefore directly attacked the machine with a low-priced model of the Linotype, called the Linotype Junior, in 1901. In addition, whenever a Thorne machine was traded in for a Linotype, rather than sell the machine on the used market, it was scrapped. In this way, Mergenthaler lowered the installed base of machines and made the production of replacement parts less economical. This competition eventually drove the product from the market, and production ceased in 1913 after about 2000 machines had been built.

Burr-Empire

Another potential competitor was the Burr-Empire machine. This machine was developed by users -- a printing shop -- and preceded the Linotype, with primary patents filed in 1857. The shop eventually began marketing the machine, and a number were installed at the *New York Tribune.* In fact, it was one of these machines that the original Linotype replaced in 1886. Mergenthaler purchased the firm in 1904, and production of the Burr-Empire ceased. A total of about 175 machines had been made.

Figure 4.5

The Thorne Typesetter



Source: *Scientific American*, July 23, 1887

Figure 4.6

The Burr Typesetter

THE BURR

Type-Setting and Distributing Machines,

63 TO 71 FRANKFORT AND 22 JACOB STREETS, NEW YORK, U. S. A.

THE ABOVE CUT REPRESENTS THE TYPE SETTER AND DISTRIBUTER, WHICH IS

THE ONLY AUTOMATIC PRACTICAL WORKING MACHINE IN EXISTENCE!

The capacity of the Machines is in accordance with the ability of the Operator, as is shown by the following test of 13 pairs for the past five years, average per day of 9½ working hours.

ONE PAIR.	Over 60,000 Ems—Distributed and Set.	FIVE PAIR.	Each 46,850 Ems—Distributed and Set.
THREE PAIR.	Each 55,200 " " " "	FOUR PAIR.	" 43,700 " " " "

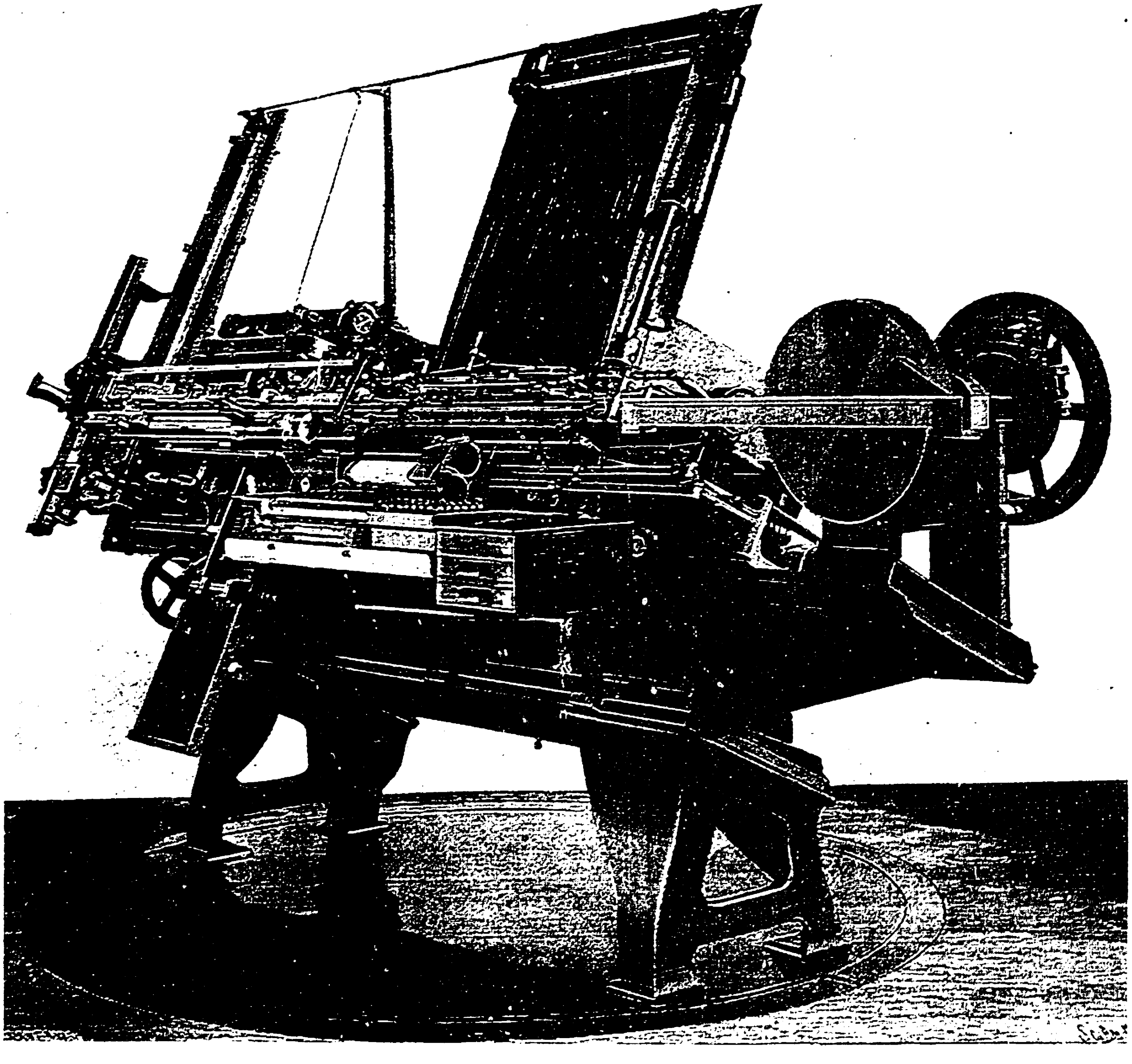
The Machines are Built to Set & Distribute Small Pica, Long Primer, Bourgeois, Brevier, Minion and Nonpareil.

Minion & Nonpareil Machines can be seen in operation at N.Y. Tribune Office. Brevier Machines can be seen in operation at Mr. Geo. Munro's, 27 Vandewater St., N.Y. Small Pica, Long Primer, Bourgeois and Brevier Machines can be seen in operation at Burr Printing House, 18 Jacob Street, New York.

Source: *American Model Printer,* April 1883 (Huss, 1973)

Figure 4.7

The Paige Compositor



Source: *Inland Printer*, February, 1903

Paige Compositor

Perhaps the most notorious of the foundry type machines was the Paige Compositor, a machine financed by Mark Twain. This machine was "the largest, the most expensive, the most complicated, and the most productive (when running) of any of the machines designed to compose foundry type." (Goble, 1984, p.158) The complexity of the machine, with its 18,000 parts, made it highly unreliable. While two were built, it never achieved any commercial success, and Twain lost about $200,000 on the venture. Eventually Mergenthaler acquired the rights to the machine and its associated patents for $20,000 in 1898.

Hot Metal Competitors

In contrast to the foundry type machines, which imitated hand typesetting, the Linotype took a fundamentally different approach. As described earlier, it reconfigured the entire typesetting process by combining casting with the arrangement of the letters. Once the Linotype machine appeared on the market, other competitors began to imitate its technology. Initially this competition was beneficial to Mergenthaler in that it gave legitimacy to the hot metal architecture as opposed to the competing foundry type architecture. Mergenthaler, however, fought the competition. Patents provided Mergenthaler strong protection in the US market, but competition abroad resulted in the acquisition of key competitors Roger's Typograph and Monoline. Monotype was the only firm to establish a strong position before the expiration of key patents.

Roger's Typograph

John R. Roger's Typograph, announced in 1890, was one of the more successful hot metal machines. Its sales, however, were concentrated in Canada and Europe since Mergenthaler obtained an injunction preventing manufacture of the machine in the United States claiming it violated patents on the principle of casting a type slug from individual matrices. Rogers fought back with a priority claim on one of the key patents of the Linotype machine, the spaceband used for justification. J.W. Schuckers had patented the concept a few months before Ottmar Mergenthaler, and Rogers owned the patent. Mergenthaler therefore acquired Roger's Typograph for $416,000 in 1895 in order to secure the rights to the Schuckers' patent. In addition, John Rogers came to work for Mergenthaler and was the lead designer in a number of improvements to the Linotype machine over the next 15 years. Roger's Typograph machine continued to be produced by Mergenthaler's Canadian subsidiary, with a total of about 4000 sold before the product was discontinued in 1912.

Monoline

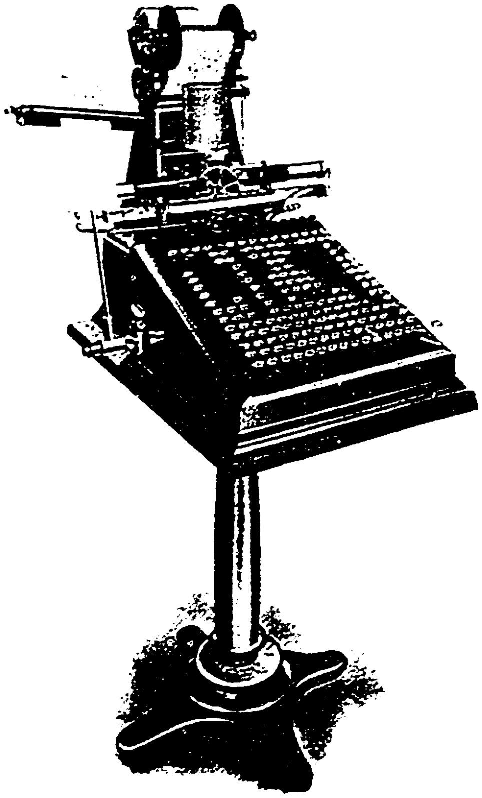
Mergenthaler also acquired another other early hot metal competitor, Scudder's Monoline, in 1905. Like the Typograph, the Monoline violated certain Mergenthaler patents, and Mergenthaler got an injunction against production in the US. The machine was however, moderately successful in Canada and Europe. About 1200 of these machines were sold, and production was discontinued shortly after the acquisition.

Monotype

The only successful early hot metal competitor was the Monotype. Introduced in 1890, it was the invention of Robert E. Lanston, a U.S. Pension Bureau clerk. The machine was unique in a number of aspects. The keyboard unit (figure 4.8) was operated separately from the output unit (figure 4.9), with a 31-channel punched paper tape interface. This allowed the output unit to be run at maximum speed since it was not limited by the speed of the typist. As its name implies, rather than cast a whole line at a time, the Monotype cast individual pieces of type which it assembled and justified. Instead of a system of recirculating matrices, the Monotype machine had a 2 x 2 matrix case which held only one copy of each character (see Fig 4.10). Under the control of the paper tape, the case moved in 2 dimensions such that the correct character was positioned over the mold when casting took place. The 2x2 matrix case could hold over 225 characters and allowed for many specialized characters to be output without intervention of the operator. The Linotype magazine, in contrast had only 80 channels to hold characters. Specialized "sorts" as they were called had to be input by hand.

Figure 4.8

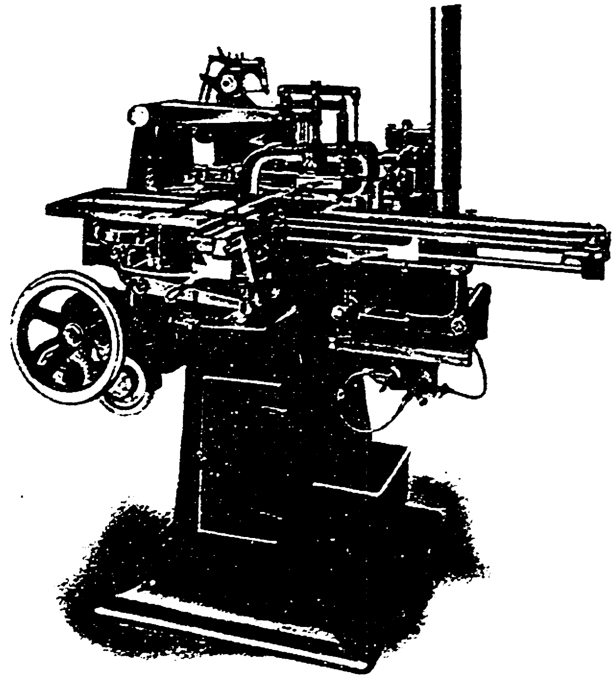
Monotype keyboard



Source: *Inland Printer*, September, 1903

Figure 4.9

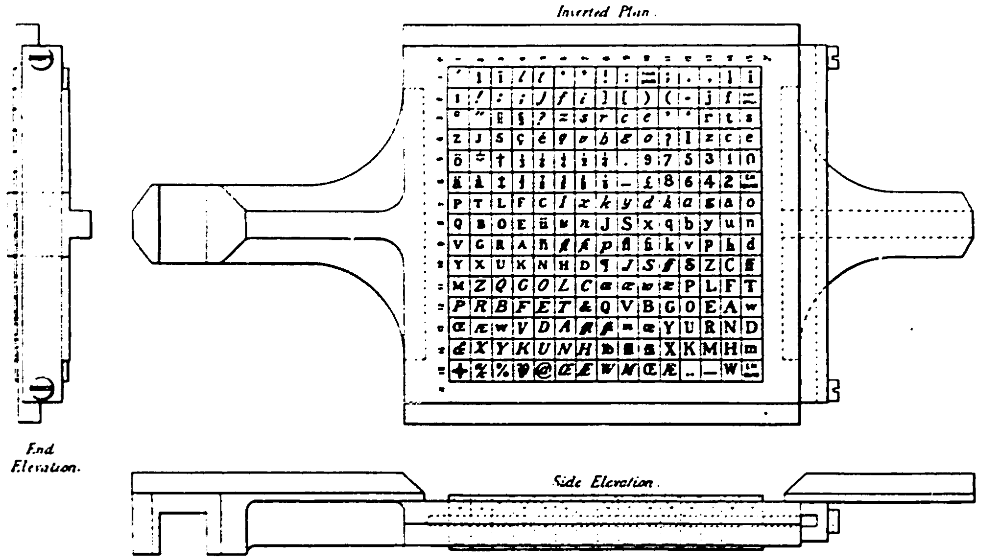
Monotoype Caster



Source: *Inland Printer*, September, 1903

Figure 4.10

Monotoype Matrix Case



Source: *Legros & Grant,* 1916

The Monotype succeeded because it better met the needs of a specialized market segment, users with complex typesetting applications. The Monotype was especially good at setting mathematical formulae, tabular material and foreign languages. Given that it had 225 characters immediately accessible as opposed to 80, the Monotype could set this material faster. Correction of errors was also simplified in that an individual character could be replaced as opposed to recasting a whole line. Typographers, firms that specialized in typesetting services, would generally own both a Monotype, for complex work, and a Linotype for straight text work. The Monotype thus found a smaller but stable segment and was quite successful in serving that segment.

4.2.4 Incremental hot metal innovation

After key Mergenthaler patents expired in 1910, firms that copied the Linotype "linecaster" architecture entered the industry: Victorline (1910), Intertype (1911), and Linograph (1912). Since Mergenthaler had established a strong position by this point in time, entry was not easy, and of these firms only Intertype was successful.[3]

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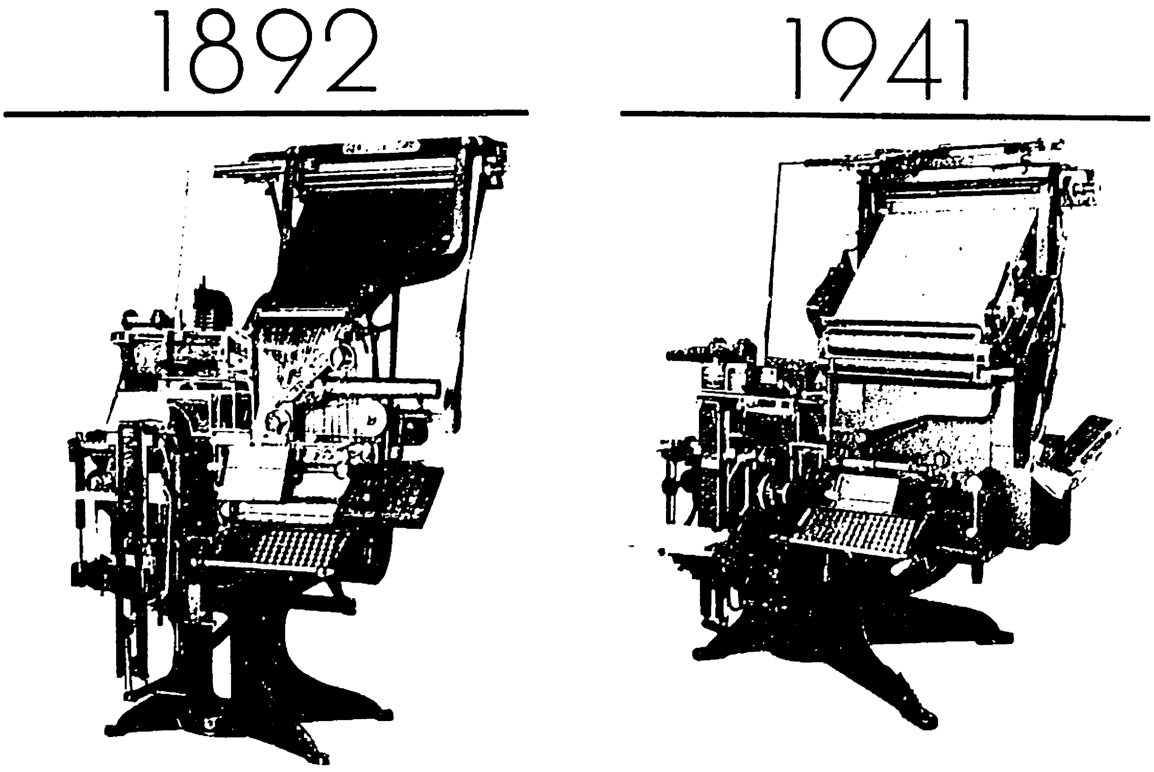
[3] Intertype's entry strategy differed from that of other new entrants in a few key dimensions. Most importantly, Intertype machines were compatible with Mergenthaler matrices, so users did not have to invest in a new set of matrices in order to use the Intertype. Intertype was also founded by ex-employees of Mergenthaler and so some of the reputation advantages of Mergenthaler may have spilled over to the new firm. Finally, low prices enabled Intertype to quickly increase production volumes and thus match Mergenthaler's cost position.

With the linecaster architecture clearly dominant, technological change in the typesetter industry was incremental, building upon the existing capabilities of the established hot metal firms. Both Mergenthaler and Intertype improved on the hot metal machine without changing its underlying architecture -- the Linotype Model 1, produced in 1892 looks almost identical to the Model 35/36 produced in 1941 (see fig 4.11). The culture of the Mergenthaler development organization was succinctly summarized by an engineer who worked for the firm in the 1950's.

> " 'Don't try and change anything Ottnar [Mergenthaler] did or you'll get in trouble,' was our motto"

Figure 4.11

Incremental Change in the Linotype machine, 1892 vs. 1941



Source: Rochester Institute of Technology, 1981

Table 4.1 lists a number of the incremental innovations made by Mergenthaler during this period. For instance, users wanted access to more than one typeface at a time, so machines which had multiple magazines of matrices were designed (e.g. models 2, 8 and 9). Other innovations such as the electric metal pot (1915) and the Micro-therm pot (1939) improved the heating of the molten lead. After fifty-plus years of this type of incremental innovation, the industry was transformed by the next wave of technology.

Table 4.1

Incremental Improvements to the Mergenthaler Hot Metal Linotype

Year	Innovation	Description
1886	Blower Linotype	Original machine
1890	Square Base Model 1	Power driven keyboard; inclined magazine
1892	Model 1	Massive square base replaced with star base
1897	Wide-measure	Maximum width increased from 30 to 42 ems
1898	Two-letter matrix	Matrices had 2 vs. 1 character punched in them
1901	Individual motors	Simplified driving of machine and took less space
1902	Four mold disk	Decreased need to frequently change molds
1903	Model 2	Two magazine machine
1903	Model 3	Allowed point sizes larger than 11 pt
1906	Model 4	Quick-change double magazines
1906	Model 5	Separate escapement mechanism saved space
1909	Water-cooled mold disk	Speeded up cooling of slugs after casting
1911	Model 8	Three-magazine machine
1911	Model 9	Four-magazine machine
1914	Model 14	Auxiliary magazine
1915	Electric metal pot	Substituted for heating metal by gas
1918	Model 20	Set display typefaces
1921	Models 21 & 22	Permitted wider faces
1924	Models 25&26	Eliminated parts for magazine escapement
1929	Swinging keyboard	Increased accessibility of keyboard parts
1931	Mechanical Thermostat	Simplified control of heat for electric pot
1931	2-in-1 Linotypes	Allowed shift from text to display range
1934	Precision Knife Block	Improved trimming of slugs
1935	Wide-standard magazine	Allowed use of wider typefaces
1936	Blue Streak Linotypes	Numerous improvements for ease of use
1939	Micro-therm pot	Improved heat distribution
1941	Models 35 & 36	Improved mixing of small and large faces
1942	Auto-ejector	Improved ejection of slug after cooling

4.3 The second generation: analog phototypesetting

Analog phototypesetters posed a tremendous change for the typesetter industry. While the effect of this shift was dramatic, the development of the basic technology was gradual, occurring outside the industry over a long period of time. In this section I briefly review some of the early phototypesetter research. I then examine the environmental factors that facilitated the commercialization of the technology. In particular, demand for phototypesetters was driven by technological changes in other parts of the overall printing system along with the emergence of a new segment of users. As in the original automation of the industry, I find that users play a crucial role in innovating. The inventors of the Photon machine, the first new entrant to the industry, were originally typesetter users.

4.3.1 Early phototypesetter research

Radically new technology often originates outside the traditional "industry." This situation is clearly evident in the case of phototypesetter technology. While hot metal firms were investing in incremental improvements to the established architecture throughout the early 1900s, a series of inventors from outside the industry were working on the development of a phototypesetter. In fact, the seeds of the new generation were laid early in the hot metal era. A Hungarian, Eugene Porzsolt, is generally credited with patenting the first working phototypesetter in 1894. His machine used a typewriter-like keyboard which elevated characters in front of a camera for photographing. Other early patents include those of Fries-Green (1895) and Richards (1899). One of the first working prototype machines was the August-Hunter Phototypesetter, patented in 1921, however "technical refinement and reliable operation eluded the inventors despite years of tenacious struggle" (Wallis, 1993, p.10). These early machines bore little resemblance to hot metal designs. Subsequent patents, however, were based upon adaptations of the Linotype or Monotype. Robertson, Brown, and Orrel (1921), Smothers (1925) and Friedman and Bloom (1926) all patented phototypesetters based upon the Linotype architecture. Over 60 patents for phototypesetter machines had been issued in the U.S. by 1940. While no commercial products resulted from this work, it laid a foundation for future technological development.

4.3.2 A shifting environment: the movement to offset printing

In the early 1900's, newspapers were the primary users of typesetters. Other segments of the publishing industry were, however, growing rapidly. By 1939, the Census of Manufacturers reported that printing and publishing of periodicals and books had grown to 45% of total output, with newspapers accounting for the remaining 55%. Most magazine and book publishers outsourced their typesetting to an increasing number of commercial typographers and printing shops. Given the importance of graphics and pictures for these growing end-user segments there was increased demand for offset printing using photographic processes. Offset lithography was much better suited to the printing of images than letterpress printing.

Any images to be used in letterpress printing were photoengraved as copper or zinc cuts and then mounted on wood blocks. These etched images on blocks were locked into place in the form, side by side with the raised letters. The process of photoengraving was time consuming, and the ability to substitute photographic processing of images was one of the clear advantages of offset printing. By 1950 offset printing still accounted for only about 5 % of the printing market, but sales of offset printers were growing at about 30% per year. The trend towards offset printing was clearly established.

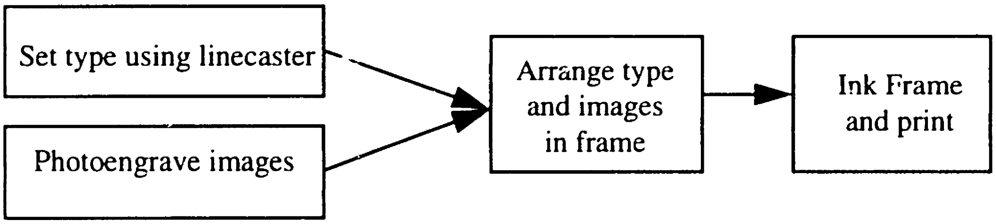
The movement to offset printing clearly influenced the development of typesetter technology. Since the output of a typesetter is input to a printer, when the form of interface required by a given printer technology changes, this change imposes new requirements on the typesetter. In this case, the increasing movement from letterpress to offset printing increased the need for photocomposition devices. With letterpress printing the required input from a typesetter was metal with raised letters. Offset printing, however, required a film positive or negative as input in order to create a printing plate. Interfacing a hot metal typesetter with an offset printer was therefore quite cumbersome. Once a frame with raised letters was ready from the hot metal machine, a single impression of the page was made. A photograph of that page was then taken and developed in order to provide the appropriate input to the offset printer. With a phototypesetter, the output of the typesetter was film ready to be used in the printing process.

If text and images were both produced via photographic processes, then film text and images could be "stripped" together on a piece of plastic the exact size of a press plate. This "flat," as it was called, would be placed, under vacuum pressure, next to a photosensitive plate. The plate was then exposed and developed in order to form a finished printing plate. Figure 4.12 contrasts three processes: hot metal typesetting and letterpress printing, hot metal typesetting and offset printing, and phototypesetting and offset printing. Clearly phototypesetters were more suited for offset printers than hot metal typesetters. The innovators in the analog phototypesetter generation recognized the mismatch between letterpress and offset and developed the new technology.

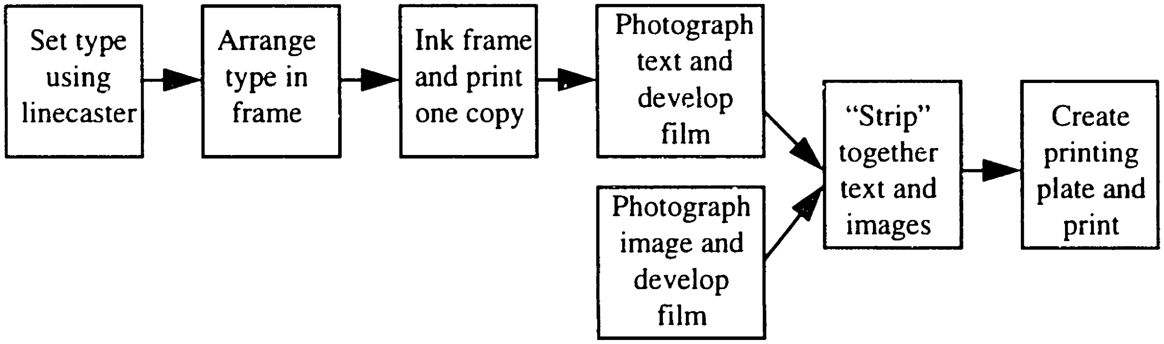
Figure 4.12

A Comparison of Typesetter / Printing Interfaces

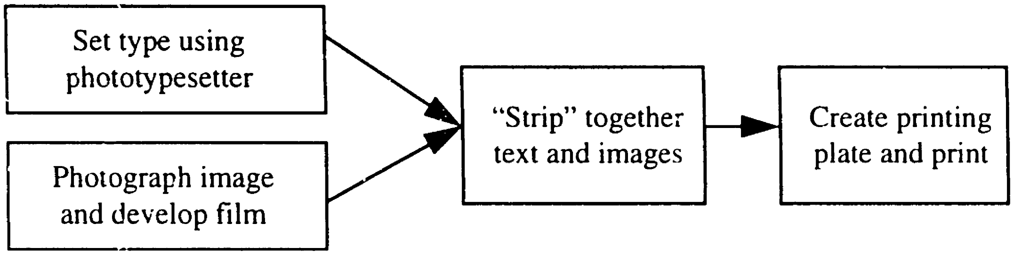
Hot Metal typesetting and Letterpress Printing



Hot Metal typesetting and Offset Printing



Phototypesetting and Offset Printing



4.3.3 Photon: the innovator

As with the original automation of typesetting, users played a significant role in the development of analog phototypesetters. Rene Higonnet and Loius Moyroud, the two Frenchmen that developed the Photon were typesetting users. In a speech describing the Photon, Moyroud describes how they first became interested in developing the machine:

> "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.
>
> Back at the office, Mr. Higonnet reported to me what he had seen. He told me of the lead they have to melt and to manipulate to produce but one single good proof. I agreed with him that it was extravagant. '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.

Once Higonnet and Moyroud had a working prototype, further development of the Photon was financed by a group of users. In 1946, searching for funding, the two inventors had demonstrated their machine to Bill Garth, president of Lithomat Corporation, a US firm that manufactured offset printing plates. Garth was impressed by the machine, and his company signed an agreement to further develop it raising about $100,000 in funds from over 150 organizations in the newspaper and publishing industries through the creation of the Graphic Arts Research Foundation. These users felt a need for phototypesetting and were not satisfied with the efforts of established hot metal typesetter firms.

The Lithomat Corporation soon divested its previous interests and concentrated on the development of the Photon machine. The name of the corporation was changed to Photon in 1950. After many difficulties, the first machine, the Photon 100 was field tested at the *Patriot Ledger* in Quincy, MA in 1954. Further enhancements were made, and the first production model, the Photon 200, was brought to market in 1956. The Photon 200 was the first electro-mechanical analog phototypesetter on the market.[4]

4.3.4 Description of analog phototypesetter technology

The Photon machine was based entirely upon electro-mechanical principles. It had three basic components: a keyboard unit, a "relay rack" and an output unit. Fig 4.13 shows the machine from the outside. An ordinary typewriter was used as the keyboard unit. It sent electronic signals to the relay rack during keyboarding and received back information such as the line length remaining in order to aid justification decisions. Once a complete line was composed it was sent to the output unit (see fig 4.14).

The output unit stored 16 fonts of 82 characters each on a spinning glass disk (see fig 4.15). The characters on the disk were transparent and the background opaque. Characters were selected by the relay circuitry and, based on timing slits on the disk, a strobe light went off just as the correct letter passed in front of the flash tube. The image of the letter passed through a lens to size it,

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[4] As discussed in Chapter 6, Intertype began shipping a phototypesetter in 1949, but the machine was mechanical and used the same architecture as hot metal machines.

and then through a collimating lens and prism before it was exposed on film. Placement of characters on the film was controlled by the mechanical movement of a carriage which held the prism and collimating lens. Key patents were filed for the stroboscopic selection of characters from a spinning photomatrix with timing slits and for width circuit boards to store character widths and point-size multiplication.

The Photon had a number of advantages over hot metal typesetters. It was a much faster machine, producing output at 10 characters per second vs. 3 characters per second. It also offered a great deal more flexibility. At most, four fonts were immediately accessible on a hot metal machine as opposed to 16 fonts on the Photon. Finally, the machine was much more reliable.[5]

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[5] Despite its auspicious beginnings, Photon never managed to establish a profitable presence in the typesetter industry, and the firm entered Chapter 11 in 1975. While there is clearly no one reason for any firm's demise, it appears that poor management - especially poor financial controls - and not technical performance, was largely responsible for Photon's problems. Discussions with ex-employees bring to light a few examples.

Early on the firm had difficulty with inventory control. For instance, ex-employees note that the firm used to manufacture an extra glass font disk for every one sold just in case a customer broke one. Since the disks were expensive and fragile, however, customers were careful and rarely broke them. The firm therefore had a huge inventory of extra disks.

Inventory problems continued with later production models. Photon licensed its technology to AM Varityper in 1967. Photon did the manufacturing and sold the original AM 725 to Varityper for about $8500 hoping to get high volumes. AM priced the machine higher than anticipated at retail - for $22,000 - and it didn't move nearly as fast as expected resulting in excess inventory. In addition, Photon had rush ordered many parts in order to have a ready supply for manufacturing, and the cost basis of the machine escalated to the point that Photon no longer made money selling it for $8500.

In 1973 it became clear that the firm had inadequate financial controls. In March the SEC suspended trading of the stock "because it appeared that Photon had not produced and could not produce accurate financial information." A subsequent 1974 report to shareholders includes a $19 million inventory write-off to adjust for "obsolescence, shortages, incorrect inventory pricing and other accounting errors." It also alerts investors that "henceforth they cannot rely upon the Company's financial reports for the period 1968-1972." The firm never really recovered from these problems, and after entering Chapter 11, the remaining assets were purchased by Dymo Industries in 1975.

Figure 4.13

The Photon 200 machine

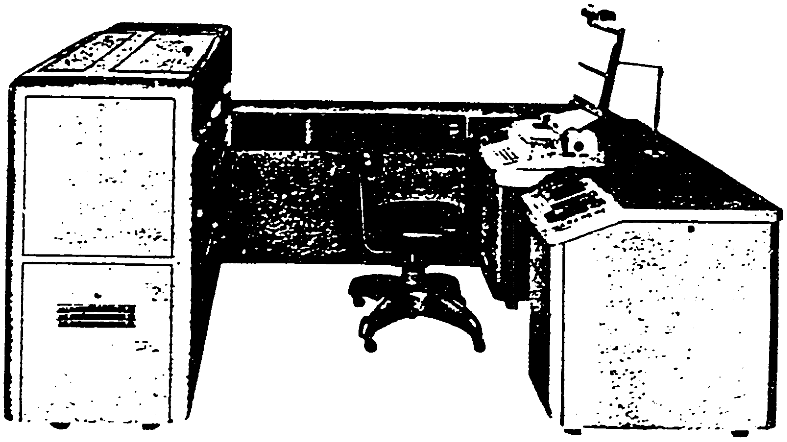
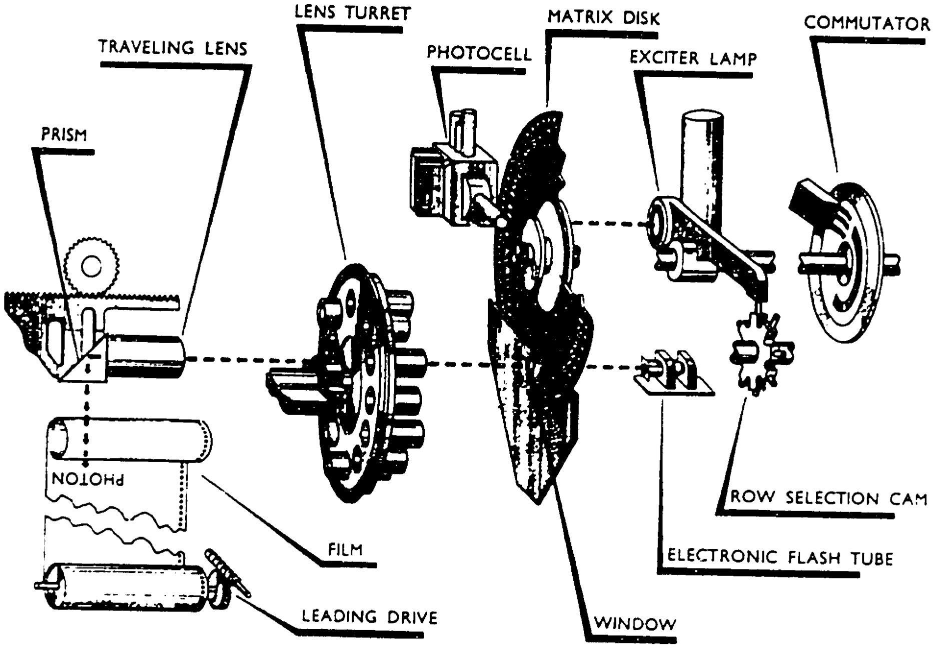


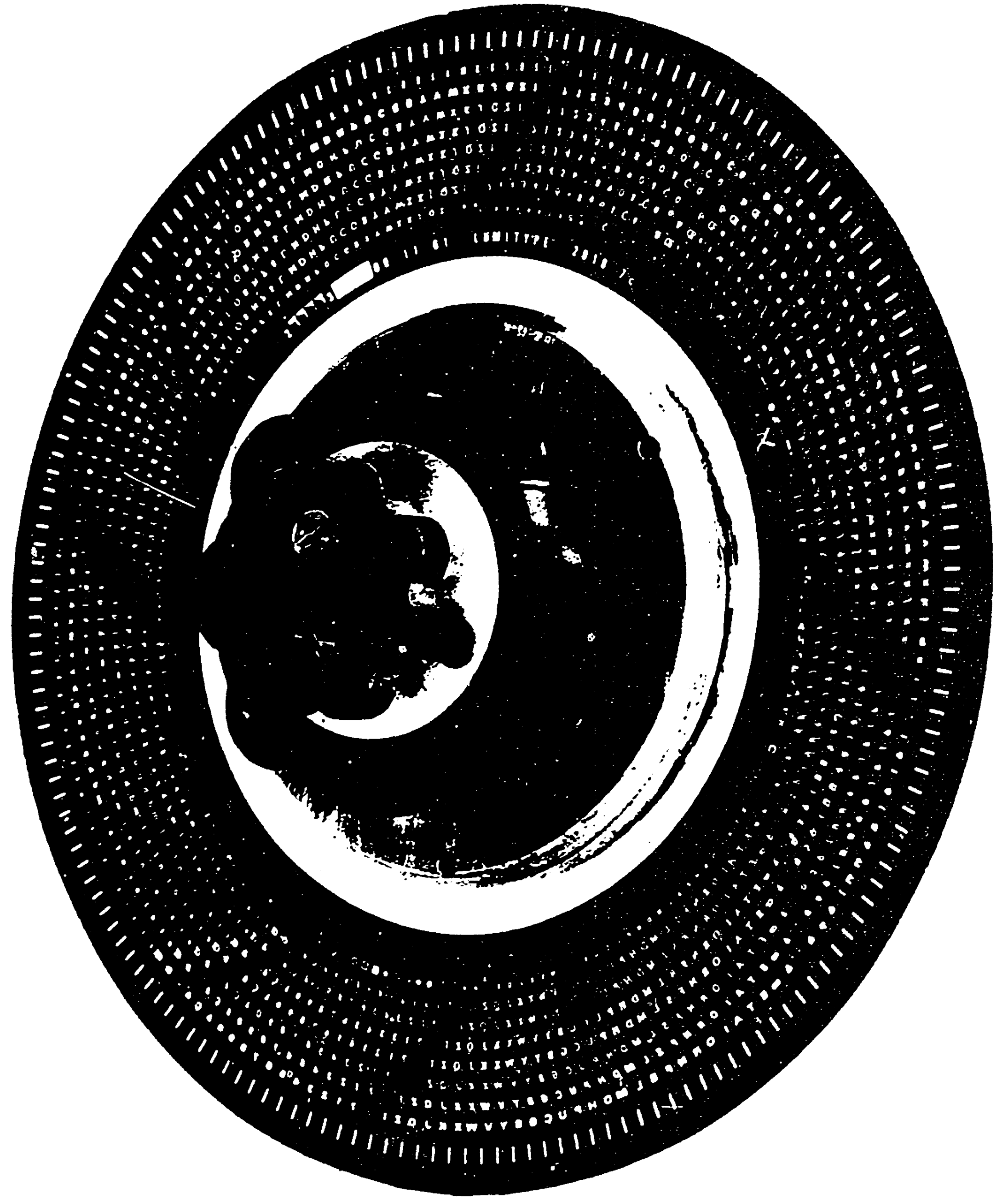
Figure 4.14

The Photon 200 machine output unit



4.15

The Photon Disk



The Photon established the basic architecture for other second generation machines. They were electro-mechanical with a keyboard, logic unit, and output unit. In some cases, as with the original Photon, the keyboard was integrated into a "direct entry" machine. In other cases the keyboard was separate from the rest of the machine with a paper or magnetic tape interface. The method of storing characters on film and selecting them varied. For instance, many models used a film strip mounted on a rotating drum instead of a spinning disk. Methods of character escapement were mechanical and varied from moving a carriage of optical elements to moving the photo-sensitive material.

4.4 The third generation: digital CRT phototypesetting

Many of the themes found in the development of analog phototypesetters are also present in the emergence of digital CRT machines. The initial technology was mostly developed outside of the "industry" and was influenced strongly by technological development in other parts of the overall printing system. In addition, user innovation continued to play an important role, with a typesetter user developing one of the original CRT machines for its own internal use.

4.4.1 The external environment: data processing and digital technology

While analog phototypesetters were substituting for hot metal machines in the processing of text, advances in two other areas, computers and digital scanning, were having an impact on future typesetter development. By the early 1960's computers were being used in many companies for data processing. The output of large databases, however, was predominantly done on a low quality, high speed line printer. When items from these databases, such as a telephone directory or catalog, needed to be typeset, the process was very slow. The data was often re-entered into a typesetting system. Even if a magnetic tape could be translated to serve as input to a typesetter, the maximum speed of the typesetters was only 20 characters per second compared to 1000 characters per second for a computer line printer. The proliferation of computer databases in electronic format created a need for a faster output device that could handle a rapid stream of input. As a 1969 industry report 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" (Auerbach, 1969).

At the same time, advances outside the graphic arts made the use of CRTs in typesetting feasible. As early as 1946, Mergenthaler Linotype had explored using cathode ray tubes in typesetting, but the resolution was too low to achieve typographic quality. By the early 1960s, however, high-resolution cathode ray tubes had been developed for applications such as aerial reconnaissance photography. These CRTs were beginning to make their way to the graphic arts with firms such as Dr.-Ing Rudolph Hell using CRTs in digital image scanners. These machines digitally scanned an image with a CRT, stored the digital data electronically, and output the image onto photographic film using a CRT. The speed of a CRT scanner was much faster than that of a traditional analog phototypesetter, and since letters could be viewed as simply another form of image, it made sense to use CRT technology to meet the need for a high speed typesetter.

4.4.2 The innovators: Hell and Alphanumeric/Autologic

The potential of CRT technology applied to typesetting was pursued by two new entrants: Dr.-Ing Rudolph Hell and Alphanumeric/Autologic.

Dr.-Ing Rudolph Hell.

The German firm of Dr.-Ing Rudolph Hell developed the first commercial CRT phototypesetter, the Hell Digiset, announced in 1965. Hell had been in the graphic arts business selling digital CRT scanners since the end of World War II, and when the firm was approached in 1964 by a telephone company about composing a phone directory on film, applying digital scanning technology to typesetting seemed a natural extension. The Digiset was moderately successful, and new models with incremental improvements continued to be introduced through 1983.

Alphanumeric / Autologic

While Hell was the first firm with a commercial CRT machine, Autologic also announced a CRT machine in 1965 for its own internal use. Originally called Alphanumeric, the firm was founded in late 1962 as a service bureau to provide computer operated high-speed graphic arts photocomposition service for the printing and publishing industries. An informational financial offering brochure in May 1964 states,

> "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 such as the type necessary for Alphanumeric's business is presently available...Alphanumeric intends to use the major proceeds of this financing in order 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 APS-2 (Alphanumeric Photocomposition System) was the first machine developed and a follow-on machine, the APS 3 was offered commercially in 1968.[6]

4.4.3 Description of CRT technology

The design of the Hell and Autologic machines was very similar, and formed the basic architecture for the CRT generation. Each of these machines initially operated at 1000 characters per second as opposed to a maximum speed at the time of about 20 characters per second for analog phototypesetters. The Hell Digiset worked as follows. A stream of previously formatted text was read from magnetic or paper tape. Via control logic of a hard-wired computer, the appropriate characters were then selected from digital storage on magnetic disk. These characters had been previously scanned by a Hell Klischograph scanner and stored on tape. The fonts needed for a particular application were then transferred from the tape to magnetic disk before the job began. Fonts were stored digitally as a series of vertical start/stop points. The image of a character was exposed onto film via an output CRT. A series of vertical strokes were painted onto the screen of the CRT and the light emanating from the CRT passed through a lens and was exposed onto film. The machine also had flexibility built in. Different sizes were produced by lengthening the strokes and spreading them further apart. A character stored as a 10-point master at 720 strokes per inch could be increased 100% in size and with a reduction to 360 strokes per inch.

The APS machine was similar to the Hell Digiset, with the following exceptions. Alphanumeric had filed significant patents for the compression of font data. The APS machine could therefore store more fonts in memory at once. In addition, it was able to economically store separate masters for each font size,

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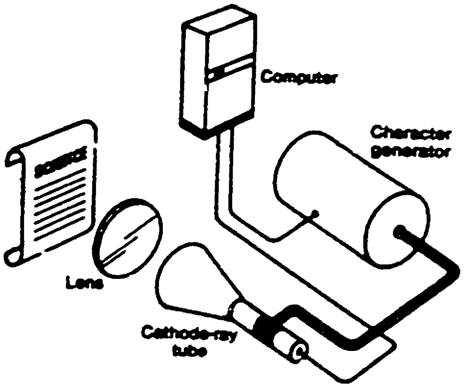
[6] In 1970, the company closed down its unprofitable service bureau operations, and the typesetter portion of the business continued under the name Autologic. The APS 4 announced in 1971 became very popular in the newspaper segment of the industry, establishing Autologic as a major player in the industry.

so different sizes did not require different resolutions as with the Digiset. Figure 4.16 shows a diagram of a typical CRT machine.

Figure 4.16

Typical Third Generation Digital CRT phototypesetter



Source: Goodstein, 1981

As CRT technology progressed, most machines began to incorporate a programmable mini-computer rather than use hard-wired control. This increased the flexibility of the machines since upgrades could be made via software. In addition, the means for storing digital characters evolved over time. Another new entrant, Seaco, announced a machine in 1971 that stored the outline of a character in memory rather than a series of start/stop points, thus saving memory space. Outline descriptions also enabled characters to be enlarged without changing the resolution, allowing for more uniform quality.

With few exceptions, CRT machines did not include an integrated front end system for the entering and manipulation of text. Given the speed of the machine, it didn't make sense to limit its output capacity to the input of a single, or even multiple typists. Separate computerized front end systems were therefore developed. As I discuss below, advances in these systems created demand for laser imagesetters.

4.5 The fourth generation: digital laser imagesetting

4.5.1 The environment: front end integration of text and graphics

Just as advances in computerized data processing drove the need for high speed CRT typesetters, continual advances in computerized front-end systems drove the need for laser imagesetters. Throughout the 1970s sophisticated multi-terminal computer systems had been developed to take advantage of the high-speed output of CRT typesetters. Newspapers, for instance, installed systems that allowed reporters to enter stories at their own terminals, and then an editor could access and edit the stories. The long term goals of these systems was 1) to display WYSIWIG (what you see is what you get) output, 2) to integrate text and graphics and 3) to produce complete pages. (interview with LA Times technology manager, 1994). A system that could produce and output complete pages of text and graphics would eliminate the time-consuming process of "stripping" where images and galleys of text were manually placed on pages (see figure 4.12). This process had continued throughout both the analog phototypesetter and CRT generations.

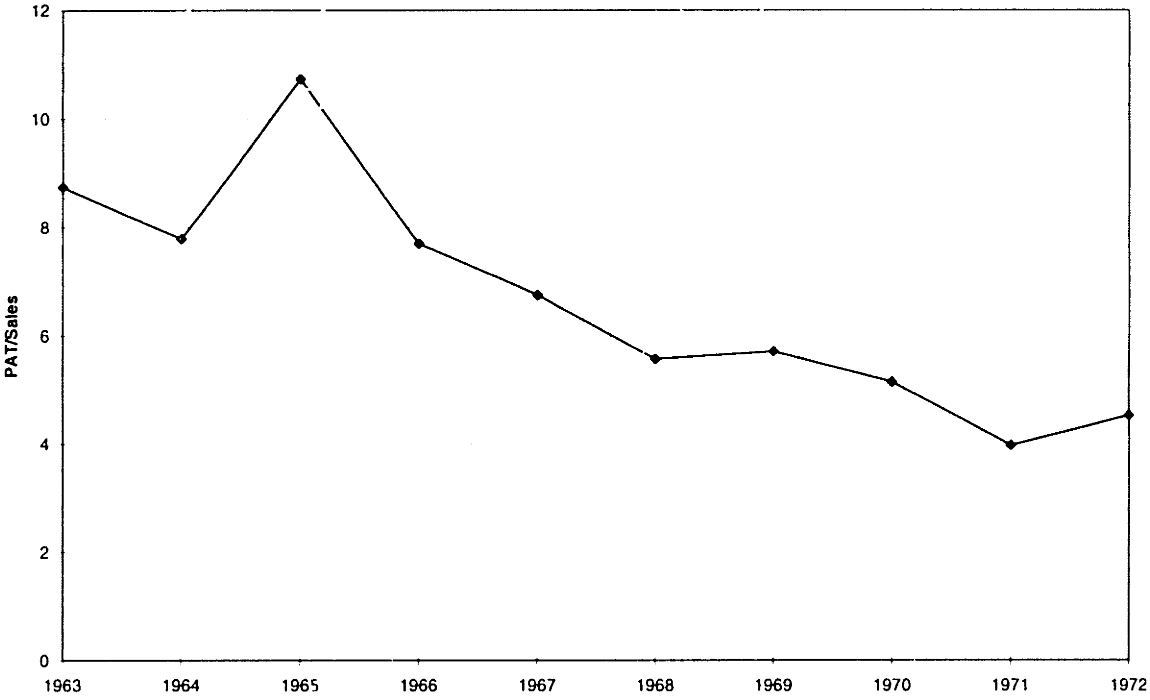
Advances in this direction were clear. In 1975, a start-up firm, Camex announced a system for making up pages that incorporated a graphic tablet linked to a video screen. An operator could sketch layout blocks on the tablet using a stylus, and they would appear on the screen. Xenotron, a British firm, announced a Video Composer in 1977 that allowed WYSIWIG output. These and other advances pointed to the clear need for a typesetter that could integrate text and graphics and could also output full pages. In the early 1970's helium-neon lasers had been used by firms such as Cognitronics and ECRM in OCR (Optical Character Recognition) scanners. Demand for full page integration of text and graphics made their application to typesetting economical.

4.5.2 The unexpected innovator: Monotype

Whereas new entrants were the innovators for prior technological generations, the first firm to announce a laser imagesetter was one of the original three hot metal firms, Monotype. By the early 1970's Monotype was clearly lagging technologically. The firm had not invested in developing a CRT machine, and its analog phototypesetters were still not competitive with the machines of new entrants. An examination of financial records shows a substantial decrease in profitability (figure 4.17). Monotype was clearly facing a crisis, and management acknowledged a need to take action. In addition, the government invested money in order to help save what they viewed as one of the "'crown jewels" of British industry.

Figure 4.17

Monotype Profitability, 1963 - 1972



Source: Seybold Report, 1973

Rather than attempting to catch up in the CRT generation, the firm decided to attempt to leapfrog the industry and began development of a radically new typesetter technology, a laser imagesetter. Under the direction of David Hedgeland, an individual with no ties to Monotype's hot metal development efforts, the Lasercomp was developed and first shipped in 1976.

4.5.3 Description of laser imagesetter technology

The Lasercomp set the basic architecture for laser imagesetters. First, the machine used a raster scan. This meant that rather than digitally write out a character at a time using vertical strokes, as the CRT machines had done, the Lasercomp created images by painting a set of horizontal lines across a page. A complete line had to be stored by the machine so that it could write out part of each letter as it did its horizontal scan (see Figure 4.18). A specialized software/hardware combination called a raster image processor (RIP) was necessary to accomplish this. The RIP served as an interface, translating the data from the input device into a series of dots for the output device. By treating letters like a graphic, raster machines were able to seamlessly integrate text and graphics on a page. With this generation machines thus became "imagesetters" not just typesetters.[7]

The second component of the laser imagesetter was the laser output recorder. The Lasercomp used a helium-neon laser, although other vendors' machines later used less expensive laser diodes. The laser was deflected across a page of photographic material by a spinning polygon mirror.

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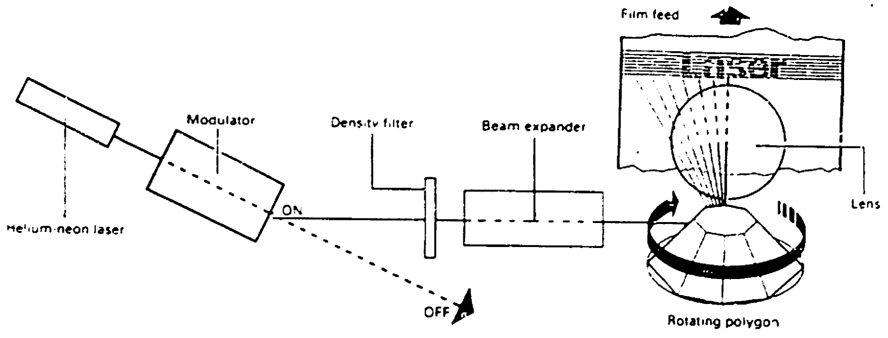
[7] Despite the clear movement towards integration of text and graphics in front end systems, users were slow to adopt the new technology, and the Lasercomp was initially used for mostly text. By the time demand for integration of text and graphics materialized in the early 1980's, there were other competitors on the market and the Lasercomp, while it did moderately well, was no longer the market leader.

Figure 4.18

The Lasercomp



4.6 The fifth generation: laser Postscript Imagesetters

Laser imagesetters were just beginning to substitute for CRT typesetters and made up only 6% of the typesetter market when laser Postscript imagesetters were introduced in 1985. Once more, a related industry, desktop publishing, changed the needs of typesetter users. The shift to Postscript was driven by the emergence of the desktop publishing industry.

4.6.1 The environment: desktop publishing and Adobe Systems

The desktop publishing industry originated in 1985 through the cooperation of a number of firms in the development of a set of related products: Apple's Macintosh computer, Adobe System's Postscript page description language and Adobe/Linotype Postscript fonts, Aldus PageMaker software, and Apple's Postscript Laserwriter printer. When combined in a system, these products enabled personal computer users to produce "publishable" printed materials that combined text and graphics.

Figure 4.19 illustrates how the system worked. Running Pagemaker software on the Macintosh, a user would create a WYSIWIG document that combined text and images. That document included licensed Linotype typographic quality fonts that had been licensed by Adobe Systems.[8] The applications program would translate its output into a Postscript language program. This program was transmitted to the Laserwriter printer where a Postscript interpreter inside the printer would "run" the program, accessing stored algorithms for specific fonts from the printer's memory. The interpreter told the printer where to place dots on the page in order to create the image. These dots were placed on the page in a raster scan, similar to how laser imagesetters worked. While the 300 dot per inch output of the Laserwriter was fine for the company newsletter, if a company wanted to develop promotional material, higher quality output was required. The solution was for a high resolution (1000 dots per inch) imagesetter to incorporate a Postscript interpreter. This option was available on the Linotype Linotronic 300.

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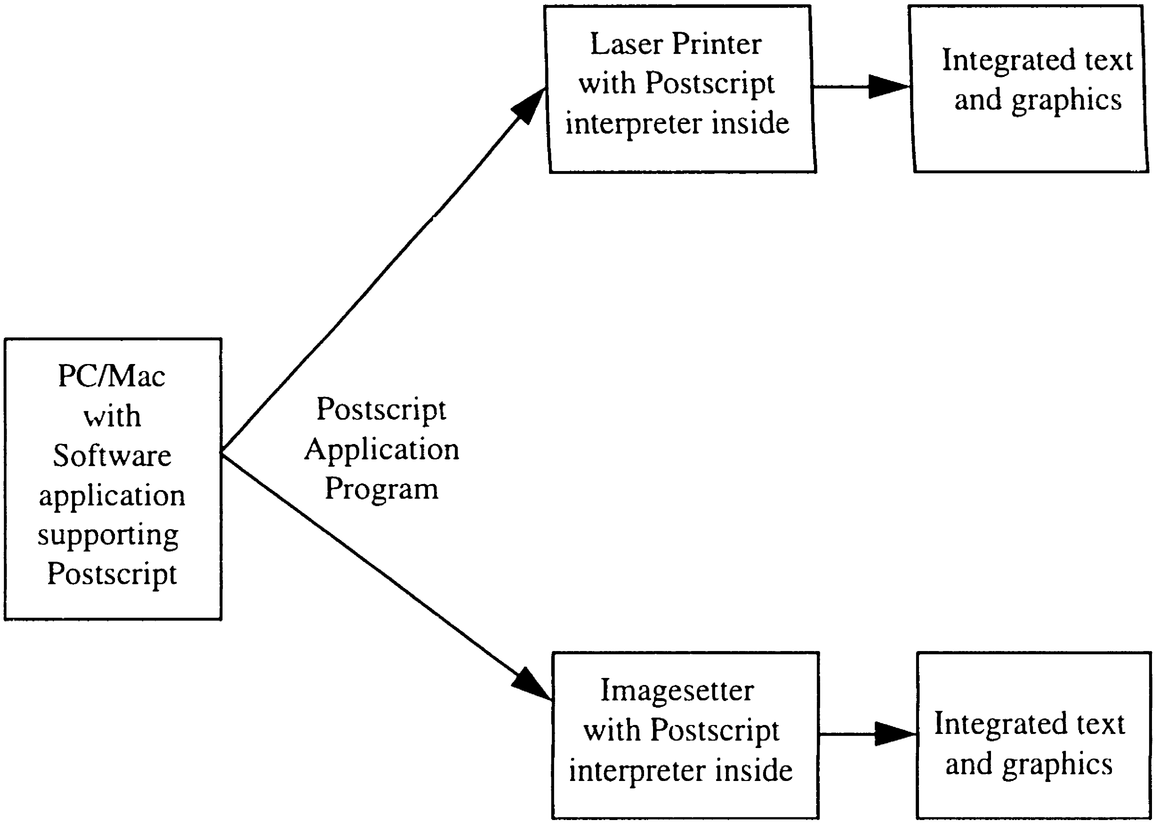
[8] An obvious question to ask is why did Mergenthaler Linotype license its fonts to Adobe Systems when it, and all other typesetter manufacturers had been unwilling to license fonts for 100 years. There are two possible reasons. First, laser printers were initially viewed as a distinct enough market that Mergenthaler Linotype may not have felt that licensing fonts for that market would have a strong effect on its traditional typesetter business. Second, since the head of Mergenthaler's typography division (along with other key employees) had left to start a company (Bitstream) that was going to provide a library of digital fonts for licensing, Mergenthaler may have felt that it needed to license its own fonts in order to preempt Bitstream.

Figure 4.19

Postscript process



4.6.2 Influence on the imagesetter market

The capabilities of desktop publishing software improved rapidly, and the user base expanded beyond corporate personal computer users to include traditional graphic arts segments such as publishers, graphic artists, typographers and printers. Purchases of specialized graphic arts front end systems were being replaced by purchases of general computers that could run desktop publishing software that created Postscript output. The combination of a new set of corporate users that occasionally wanted high quality output, and the graphic arts users that consistently wanted high quality output created high demand for Postscript imagesetters. By 1989 all the major imagesetter manufacturers had introduced Postscript machines. Sales of the machines rapidly took over other laser imagesetters. By 1990, Postscript machines made up about 30% of imagesetter sales and by 1993 about 85% of sales.

4.6.3 The innovator: Adobe Systems

As with other technological advances, Postscript had its origins outside the typesetter industry. Postscript was based on Interpress, a page description language developed at Xerox PARC. Interpress was used as an interface to Xerox high speed electronic laser printers. Two Xerox engineers, Dr. John Warnock and Dr. Charles Geschke left the firm in 1982 to start Adobe Systems and develop Postscript. They had originally planned on developing Postscript for use in their own laser printer, but when Steve Jobs of Apple approached them in 1983, they agreed to collaborate on the Laserwriter. As discussed above, this collaboration helped to spawn the desktop publishing industry.

4.6.4 Description of Postscript technology

Postscript technology provided two major advantages over other raster image processors used in the graphic arts. First, the Postscript language was device independent. A Postscript language file created by an application program could be interpreted by both a low quality laser printer and a high quality imagesetter. The interpreter would take into account the characteristics of the particular device in translating the program into marks on the page. Second, Postscript's method of encoding fonts incorporated multiple proprietary advances. It allowed for easier manipulation of fonts, including, for instance, scaling and rotation. It also incorporated a "hinting" technology which enabled much higher quality output lower resolutions. Adobe Systems describes the technology as follows (Adobe Systems 10K filing, 1986)

> Postscript is a systems software program that interprets Postscript language commands to describe the appearance of a printed page by communicating where each character (in a given typeface), line, curve, or image is to be placed on a page. Once a page is described in terms of the Postscript language, any raster output device than contains a Postscript interpreter can produce the page. As a result, users may select among a variety of output devices containing Postscript...The Postscript interpreter normally resides in a dedicated processor board, commonly referred to as a controller, inside the raster output device... Most raster-based technologies for type store the actual dot-by-dot representations, or "bitmaps," of each character...The Postscript interpreter utilized proprietary technology to represent each character in a typeface by a precise mathematical definition of the geometric outline of the character's shape. This geometric representation, once stored, can be scaled to any size, rotated to any angle, filled with black or color, outlined or used as a general graphic shape. This technology is also resolution independent."

4.7 Summary

Typesetting has clearly undergone significant technological change over the past hundred years, and continues to evolve. After sixty years of stability with hot metal technology, the industry has been shaken by increasingly frequent technological change as seen in figure 4.20. While hot metal typesetters dominated the industry for 71 years, analog phototypesetters were dominant for only 16 years, CRT machines for 7 years, and laser imagesetters never reached over 50% of the market before Postscript laser imagesetters emerged.

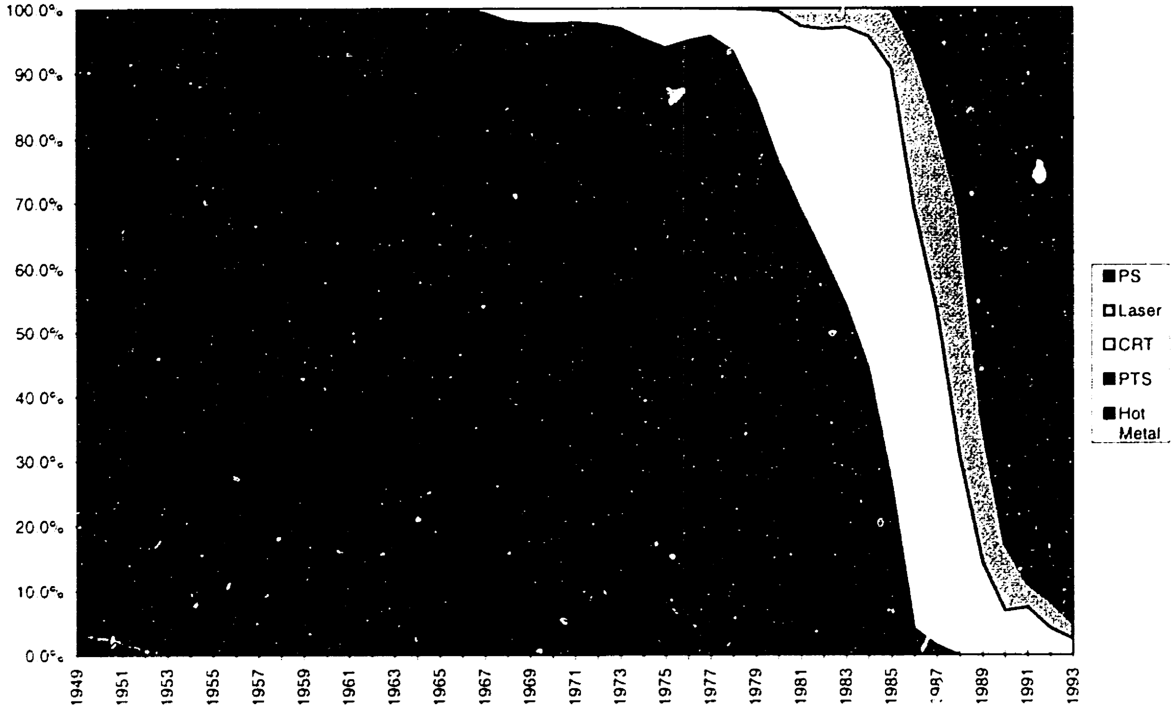
As discussed throughout, several consistent themes emerge from examining these five generations of technology. First, most of the technological changes in typesetting originated outside of the industry. Advances in electronics, computers, CRTs, lasers and software all had significant impact on the typesetter industry. For the most part, new entrants were responsible for introducing this technology to the industry.

Users played a major role in identifying the need for change and implementing it. Newspapers funded both the development of the original Linotype machine and the first analog phototypesetters. In addition, a typesetting service bureau was responsible for the development of one of the first CRT machines.

Finally, changes in the composition of users and in the needs of existing users has driven a great deal of technological change. Many user needs have been derived from changes in other parts of the printing value system. Since a typesetter provides input to a printer, changes in printing technology clearly require changes of typesetters. Similarly, changes in the way data are manipulated, including the evolution of computerized data processing, have imposed new requirements on typesetters.

Figure 4.20

Typesetter Technology Substitution, 1949 - 1993



Source: author's analysis

While this study focuses on the industry through 1990, current technological developments are exciting enough to at least warrant mentioning. The first advances are in the arena of color. Imagesetters are increasingly becoming color digital image processors, and as the resolution increases and color screening technology improves, they are beginning to compete with more traditional chemical based methods of color image production. It will be interesting to see how the convergence of these two previously distinct industries affects competition.

Second, imagesetters are turning into "platesetters" with "direct-to-plate" machines. Rather than produce film which is then used to create a printing plate, these systems write directly onto a photosensitive printing plate, eliminating the need for the intermediate step.

Finally, as we move into an era of increasing electronic communication user needs continue to evolve, and some argue that printing will no longer be necessary. If this is true, the implications for typesetting are clearly significant! It will be interesting to see what the future holds.

Chapter Five

The Effect of Technological Change on Barriers to Entry

5.1 Introduction

In Chapter Two I developed a framework for understanding how established firms might survive competence-destroying technological change (Figure 5.1 reproduces that framework). I argued that if a competence-destroying shift does not destroy other barriers to entry, then those barriers might provide the incumbents a buffer, allowing them to succeed despite initially inferior technical performance. The purpose of this chapter is to categorize each of the technological generations described in Chapter Four in terms of its effect on current competence and its effect on other barriers to entry.

Figure 5.1
Hypothesized position of incumbents vs. new entrants given technological change

Current Competence Destroyed?	No	Yes
Yes	Incumbent survives, depending on relative magnitude	* Entry increases * New entrant performance advantage
No	* Entry deterred * Incumbent performance advantage	New entrant succeeds, depending on relative magnitude

Other Barriers to Entry Destroyed?

5.2 The effect of each generation on current competence

In order to understand how each generation of technology affected the current competence base of established firms, I use two measures. I first examine changes in the required skills of individuals on a product development team for each generation. This measure, however, fails to capture any sense of architectural change in the product. I therefore also compare the product components, interfaces, and overall machine logic in order to gain a better understanding of architectural change. These two analyses are discussed below.

5.2.1 Changes in the required skill base

My analysis of the skills required to develop a product in each generation of technology is based on an examination of the staffing of a subset of product development efforts. In many cases I was able to obtain archival records of project staffing. Where staffing records were unavailable, I met with development engineers and asked them for their best recollection of the composition of the development team.

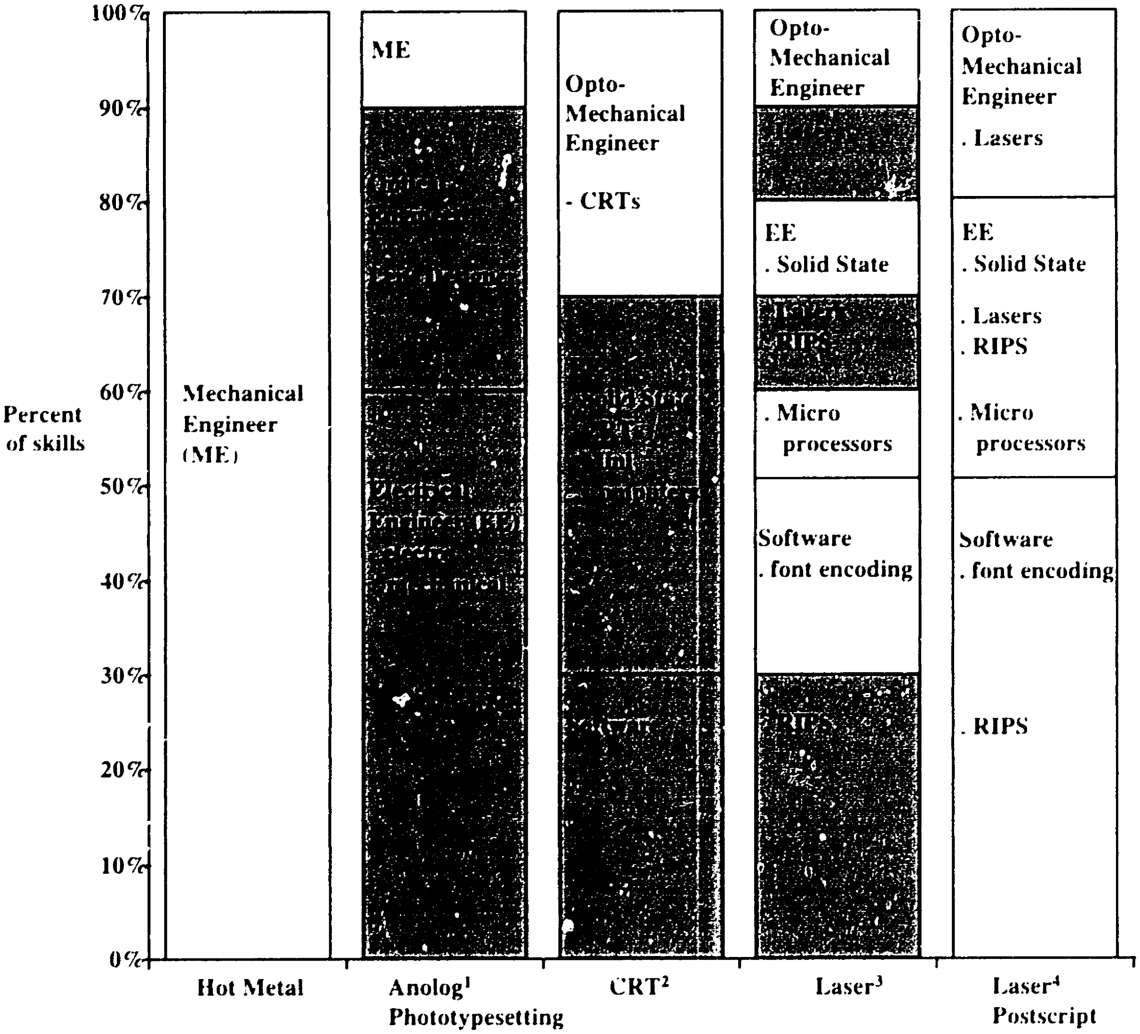
Using this information, I computed a number called "skill loss" to describe the percentage of skills that were new in each generation. If a majority of required skills were new, then a firm from the prior generation experienced a loss of skill in the sense that the relative value of its existing skill base decreased. I classified a generation as competence destroying from the standpoint of skill base if 50% or more of the skills in a generation were new. The result of this analysis is shown in Figure 5.2.

The second, third, and fourth generations of typesetter technology were all competence destroying in that a large percentage of new skills were required, and the relative value of the old skills therefore decreased substantially. In the shift from hot metal to analog phototypesetting, the development team went from all mechanical engineers to only 10% mechanical engineers. New knowledge about electronics and optics was required. Not only were generic mechanical engineering skills less valuable, but specific knowledge of the intricacies of hot metal machines also lost its value.

In the subsequent shift to digital CRT phototypesetting, there is once more a significant change, with a 70% turnover in skills. While mechanical engineering and optical engineering skills were still valuable, the skills required of electrical engineers changed substantially. Electrical engineers with knowledge about integrated circuits and CRTs were now needed. In addition, expertise in the manipulation of analog film images was no longer valuable and instead expertise in software and the formation of digital characters was required. The training needed to write software differs substantially from that needed to design hardware, and the firms' hardware expertise was therefore not directly applicable.

Figure 5.2

Typesetter Development Team Skills, By Generation



Generation	First	Second	Third	Fourth	Fifth
Skill Loss	N/A	90%	70%	50%	0%
Competence Destroying	No	Yes	Yes	Yes	No

▨ New Skills

Based on development of

1 Linofilm, Linofilm Quick, Photon 200, CG 2961,
2 CG videosetter 8400, Linotron 505, V T CE6400
3 Linotronic 101, 100, CG 9400
4 Linotronic 300, CG 9600

Laser imagesetter technology was also competence destroying in that 50% of the required development skills were new. Once more the relative value of existing skills decreased substantially. With this generation, the need for knowledge of CRTs was replaced by a need for understanding lasers. In addition, since typesetters began to set a combination of text and graphics, traditional typesetter firms needed to develop an understanding of graphics. Knowledge of "halftones," for instance, a method of using dots to represent an image, as well as knowledge of screening techniques became essential. Finally, whereas programmable minicomputers had been used to control CRT machines, microprocessors came into wider use with laser imagesetters.

Laser Postscript imagesetter development used the exactly the same set of skills as laser imagesetter development and was therefore not considered competence destroying.

5.2.2 Architectural changes

A simple comparison of skills fails to capture any changes in the architecture of the machines from different generations. By examining the characteristics of the overall product architecture relative to the preceding generation, I find that all three competence-destroying generations from the standpoint of the skill loss measure, are also competence destroying from the standpoint of their effect on architectural knowledge. In fact, in many of these technological shifts, both product components and interfaces change. I examine the controlling machine logic, the method of character escapement, the method of font storage, and the method of character output for each generation. This information is summarized in Table 5.1.

Table 5.1
Effect of Typesetter Technological Innovation on Architectural Knowledge

Innovation	Controlling Machine Logic	Escapement	Font Format	Character Output	Effect on architectural knowledge
Hot Metal Incremental Innovations	Mechanical	Mechanical	Metal Matrix	Hot Metal	Enhance
Analog Phototypesetter	Electro-mechanical	Mechanical	Film	Xenon Flash	Destroy
Digital CRT phototypesetter	Electronic/software; programmable minicomputer	Mechanical / electronic	Digital start/stop pattern	CRT strokes	Destroy
Laser imagesetter	Electronic/software; micro-processor	Electronic	Proprietary digital outline	Laser raster strokes	Destroy
Laser Postscript imagesetter	Electronic/software; micro-processor	Electronic	Standard Postscript digital outline	Laser raster strokes	Enhance

In the hot metal machines, everything from the selection of characters to line justification was controlled mechanically. The architecture of analog phototypesetters was totally different, with electro-mechanical as opposed to mechanical interfaces. Problem solving was therefore of a totally different nature. For instance, design problems associated with stroboscopic selection of a character from a spinning film disk replaced problems associated with the mechanical recirculation of matrices.

In contrast to the electro-mechanical movements of the analog phototypesetter machines, the CRT machines were purely electrical with hardly any moving parts, once again changing the basic architecture. Finding the correct character to expose on film was no longer an electro-mechanical problem, but instead a matter of using software to look up electronically stored information. Quality of the image depended upon the accuracy of CRT stroke placement and CRT resolution, as opposed to the timing of a flash and the movement of the film image. Escapement, however, was still often done mechanically by traversing a lens across the photosensitive material.

Laser imagesetters changed the basic architecture once more in that complete pages of output as opposed to galleys were produced, and these pages were produced via a raster scan. Escapement after the exposure of a letter was not longer an concern. The laser wrote out complete lines that included parts of both letters and images. The 1986 Compugraphic Annual Report emphasized the importance of laser technology stating,

> "Laser technology offers the potential for an even greater revolution in pre-press production than the one that occurred when photomechanical typesetting began to displace hot metal 20 years ago...Properly integrated into new products, lasers simplify the storage and production of combined text and graphics, significantly reduce the cost of producing initial proofs without sacrificing quality, and provide a higher quality of printed type than ever before."

Postscript laser imagesetters had the same architecture as laser imagesetters.

5.3 The effect of each generation on other barriers to entry

Other barriers to entry is a composite measure that includes a number of separate elements. Of the barriers to entry discussed in Chapter Two, those listed in Table 5.2 were judged to be the most relevant in the typesetter industry based on discussions with industry participants and entrants. Table 5.2 summarizes how each typesetter generation affected other barriers to entry relative to the prior generation.

Table 5.2
Effect of Typesetter Technological Generations on Other Barriers to Entry

Innovation	Minimum Efficient Scale	Sunk cost investment in font library	Reputation	Compatibility with other vendors	Compatibility with prior generation	Destroy other barriers to entry?
Hot Metal Incremental Innovations	High	High	High	High	High	No
Analog Phototypesetter	Much lower	Lower	Much lower	Same	Low	Yes
Digital CRT phototypesetter	Same	Same	Same	Same	Low	No
Laser imagesetter	Same	Same	Same	Same	Low	No
Laser Postscript imagesetter	Lower	Much lower	Same	Much lower	High	Yes

Note: "same" = same as previous generation; "lower" = lower than previous generation

5.3.1 Hot metal incremental innovation

Barriers to entry in the hot metal era were quite strong, and incremental technological innovation did not destroy these barriers. If anything, incremental innovation served to enhance them. I next describe the nature of these barriers, with a focus on Mergenthaler Linotype the dominant player.

Minimum Efficient Scale

Economies of scale provided the strongest barrier to entry in the hot metal generation. The combination of a high minimum efficient plant scale relative to the size of the industry and the sunk cost nature of investments in manufacturing precluded cost effective entry.

As the Linotype linecaster architecture became dominant, the typesetter industry had become increasingly concentrated, with three firms controlling 99% of the market by 1916. Since both Mergenthaler and Intertype did the majority of their manufacturing in an single plant in the United States, the minimum efficient plant scale was quite large relative to the size of the industry. Both firms also made ongoing investments in upgrading their manufacturing facilities. In the 1925 Annual Report, Mergenthaler Linotype reported that its Brooklyn works could produce 4000 Linotype machines and 75 million matrices a year -- "greater than all other composing machine factories in the world combined"(p.6).

Given the specialized nature of the manufacturing equipment, investments could be clearly viewed as sunk costs. The Linotype Bulletin (1950) described the matrix manufacturing facility stating, "On the 300-foot floors of the matrix factory are rows of machines so ingenious and elaborate that a single one represents a small fortune." The sunk cost investment in dedicated machinery indicated a clear commitment to maintaining production volumes. Since the market for hot metal machines also reached its peak in 1923 and was no longer growing (see figure 5.3) there was clearly not room for an entrant to achieve the volume required for minimum efficient scale, and cost effective entry was precluded.[1] Incremental innovation in hot metal did not significantly change

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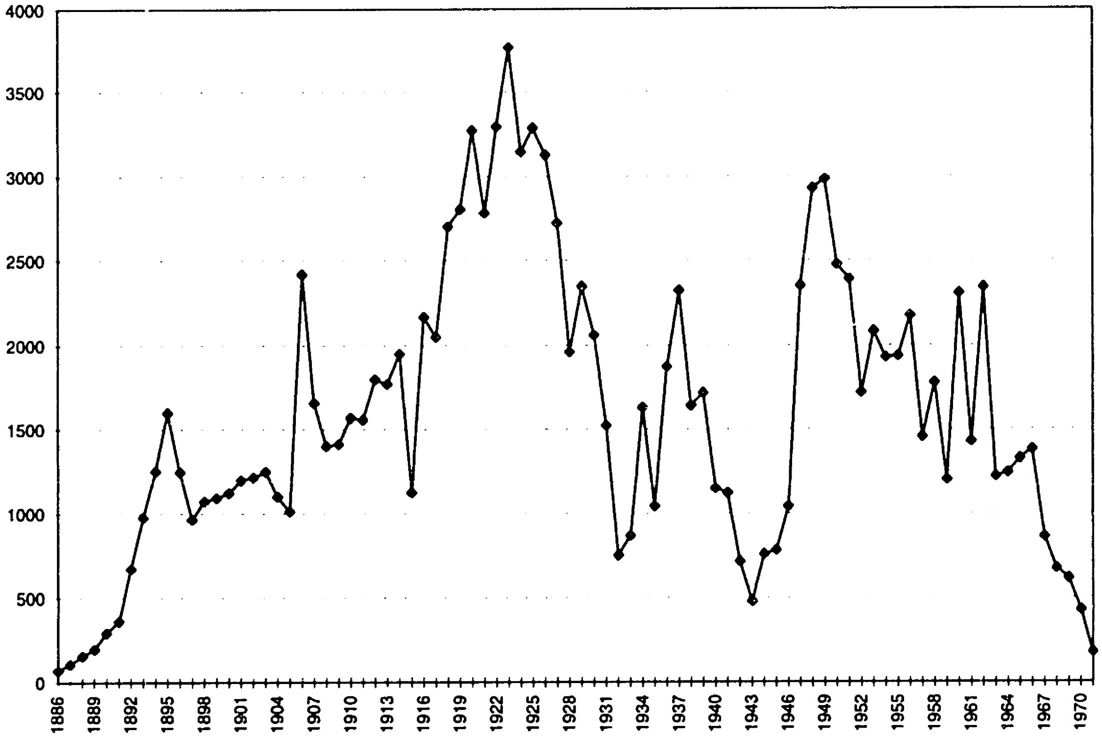
[1] Monotype operated at a lower scale, but it was manufacturing a very different machine for a much smaller segment of the market (only about 200 machines per year) and had a monopoly on that segment. A new entrant in that segment would have difficulty reaching Monotype's scale.

manufacturing requirements of manufacturing scale and therefore had no effect on economies of scale as a barrier to entry.

Figure 5.3

Hot Metal Industry Unit Sales, 1886 - 1970



Source: Mergenthaler Linotype, Monotype & Intertype archives; Goble, 1984; author's analysis

Sunk cost investment in font library

The size of the incumbents' font libraries also served to make entry difficult. As early as 1895 Mergenthaler's annual report stressed the need to invest in typeface development in order to appeal to users beyond the traditional newspaper market. Both commercial printers and typographers required a much broader selection of typefaces to make an automated machine worthwhile. In

1902 Mergenthaler had a library of over 100 typefaces. By 1913 that number had reached 1000, and by 1923 it had reached 2000. Despite investing more in typeface development than in R&D, it was taking Mergenthaler at least a year to develop 100 typefaces. At that rate, it would take an entrant 20+ years to duplicate Mergenthaler's library.[2] Monotype and Intertype made similar investments in developing a font library.

Reputation

Mergenthaler, Intertype and Monotype had established strong reputations for reliability and service in a market where those factors were crucial. Typesetting was on the critical path for newspapers to go to press, and malfunctioning machines could mean not getting the paper out in time. Typographers generally had fewer machines than newspapers, with small shops owning only one or two. If a typographer's only machine stopped working, it could not do business. Convincing buyers to undergo the risk of a new machine was therefore a considerable barrier to entry. The incremental nature of technological change did not affect this barrier. Since incremental changes did not result in a new segment of customers the reputations of established firms continued to have value.

Compatibility with other vendors

Even if a new entrant were able to develop a large font library, customer switching costs might preclude entry. Since the investment in matrices ran anywhere from 10 to 30% of the cost of the machine itself, the switching costs of moving to a new vendor were substantial if that vendor's machine could not use Mergenthaler/Intertype matrices. In addition to the cost, there were often

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[2] Many of today's well-known typefaces, such as Helvetica, were copyrighted by Mergenthaler during this era. Once it became clear in a 1970 court decision that fonts could not be patented, these copyrights became critical for intellectual property protection of fonts.

particular fonts that a user needed, and those fonts were only available from the vendor that designed it since firms did not license fonts to one another. As a result, when Linograph entered the industry in 1911 with a machine that could not use Mergenthaler matrices, it had very limited sales.

The prevalence of linecaster machines also resulted in indirect network externalities. As the installed base grew, specialized training schools for Linotype/Intertype operators emerged and created an ample supply of labor. Individuals with experience in repairing these machines were also more readily available, and a market for spare parts developed, lowering the price of repairs. Since technological change was incremental, the labor supply and service network continued to serve as a barrier to entry. It would have been difficult for a new entrant to reach the critical mass required to create a similar infrastructure.

Compatibility with prior machines

Since technological change in the industry was incremental, Mergenthaler, Intertype and Monotype made new models upwardly compatible with old ones, and a customer could therefore continue to use its font matrices on new machines. Switching to a new entrant for an incremental upgrade therefore cost the customer more than just the price of the machine.

5.3.2 Second generation: analog phototypesetters

Most of the barriers to entry that had built up in the hot metal generation came crashing down with the introduction of analog phototypesetters. Minimum efficient manufacturing scale decreased significantly relative to the size of the market, and the emergence of new customer segments diminished the importance of reputation and investments in a font library. While the need to invest in a font library remained as a barrier for existing segments, the overall level of barriers to entry was much lower than during the hot metal generation. This generation is therefore classified as "destroying" other barriers to entry.

Minimum Efficient Scale

The minimum efficient plant scale and up-front investment needed to start manufacturing decreased substantially in the movement from hot metal to phototypesetting. Production of hot metal machines and matrices required highly specialized machine tooling and sophisticated metal shops. Phototypesetter production required much less specialized equipment. The electronic components used were similar to those used in other electronic products, and some manufacturing was outsourced, a rare occurrence in hot metal manufacturing.

Sunk cost investment in font library

The sunk cost investment needed to develop a font library remained a barrier to entry, although the growth of the small newspaper segment lowered it to some extent. Since newspapers require fewer fonts, the emergence of new newspaper customers created an opportunity for firms to enter without immediately developing a substantial font library.

In serving other segments, however, established firms still had an advantage. While established players had to transfer hot metal typeface designs to some form of photographic material, the fact that they already had a large library of designs to work from decreased the cost significantly compared to that of potential new entrants. New entrants had to either attempt to license typefaces, slowly design typefaces on their own, or attempt to copy the faces of an established firm. Established firms were not willing to license their typefaces, and designing new typefaces was extremely time consuming. While some players did simply attempt to copy typefaces, this process was much more difficult than originally anticipated. For instance, despite investing significant amounts in typeface development, it took Compugraphic, the most successful new entrant, 10 years to acquire 1000 typefaces, and most of these faces were simply copies of Mergenthaler designs. The quality of these copied typefaces was generally considered inferior to the original faces. In addition, the original faces had brand names which were protected by copyright. Customers preferred the true "Palatino" to some "cheap imitation." The investment to develop a font library was thus still large relative to the size of the market, and, other than for the emerging small newspaper sector, continued to serve as a barrier.

Reputation

Reputation of the established players was partially destroyed as a barrier to entry given the emergence of new buyer segments. All else being equal, historical buyers had a preference for an established firm with a reputation for reliability. The emergence of phototypesetting, however, expanded the potential market through the growth of the small newspaper segment and the emergence of the in-plant segment (organizations doing in-house publishing). Since new buyers did not have prior relationships with vendors, the reputation of the incumbents was not nearly as strong with them and did not serve as a strong barrier.

Compatibility with other vendors

If an established customer had need of a particular typeface that was only available from its historical vendor then there would be switching costs associated with changing vendors. In order to meet the needs of *its* customers, for instance, a typesetter buyer might feel it essential to provide certain typefaces. As a commercial typographer wrote to a new phototypesetter entrant,

> "Naturally, I understand that you have many typefaces available ... My problem, however, is to perfectly match our present typestyles -- all of which are Mergenthaler faces. We are in the middle of converting from

> hot to cold type and have many cautious customers who want the same quality that hot type produces. I'm sure you can see our predicament."
>
> (Compugraphic Correspondence, 1983)

The need for specific typefaces therefore created a switching costs that continued to serve as a barrier to entry.

Compatibility with prior generation

If a customer was planning to move from hot metal to phototypesetting and did not have need of a particular font, then the cost of changing vendors at the same time was minimal. Incumbent machines were not compatible across generations. The customer would have to invest in replacing metal matrices with film fonts whether it stayed with the same vendor or moved to a new one. Similarly, the investment customers had made in training operators on the hot metal machines became obsolete when customers moved to any true second generation machine, whether made by an incumbent or a new entrant.[3] So the cost of moving to the new technology was the same whether the new machine was purchased from an incumbent or a new entrant.

5.3.3 Third and fourth generations: digital CRT phototypesetters and laser imagesetters

Other barriers to entry did not change substantially in the movement from analog phototypesetters to digital CRT phototypesetters or in the subsequent movement to laser imagesetters. The reputation of incumbents and the need to

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[3] The Intertype Fotosetter and Monotype Monophoto, both of which imitated the hot metal architecture, did have an advantage in that they decreased customer switching costs by obviating the need to retrain operators. In this case, however, the technological trade-offs required to make the shift less competence-destroying for the customer were not worth it. This is in contrast to the example of RISC mentioned in Chapter 2 where, by making chips upwardly compatible for customers and therefore less competence destroying, certain manufacturers were able to maintain an advantage.

invest in developing a font library remained as strong barriers to entry. I therefore classify these generations as "not destroying" other barriers to entry.

Minimum Efficient Scale

Minimum efficient scale had already decreased enough during the analog phototypesetter generation that it was no longer a substantial barrier to entry. It stayed at about the same level in both the CRT and laser generations.

Sunk cost investment in font library

The sunk cost investment of incumbents in developing a font library remained as the strongest barrier. Incumbents from both the hot metal and analog phototypesetter generations continued to invest large amounts in font development. For example, Compugraphic, an entrant in the second generation, invested $23.8 million in font development between 1975 and 1985. While incumbents still had to scan their photographic masters in order to form digital ones, they had a distinct advantage in already having developed the masters. New entrants in both the CRT and laser generations had difficulty duplicating these libraries.

In fact, in order to help new entrants overcome this barrier, a company named Bitstream was formed in 1983. The original goal of Bitstream was to create a library of digital fonts that could be licensed by any new entrant. The firm was founded by Michael Parker, the former director of typography at Mergenthaler Linotype. Since incumbents like Mergenthaler were unwilling to license their fonts, and since it wasn't economical for a single new entrant to invest in developing a new library, Parker saw an opportunity to meet needs of multiple new entrants. Unfortunately for Bitstream, the firm started too late. As I describe in the next section, in 1985 Postscript, an open digital font standard, filled the same need Bitstream was attempting to fill.

Reputation

Reputation also remained as a barrier. Unlike the analog phototypesetter generation, the CRT and laser generations did not result in the emergence of new customer segments. For new entrants to establish a reputation within the incumbents' existing customer base was difficult.

Compatibility

Just as with analog phototypesetting, switching costs for customers that required specific fonts still remained a barrier in the CRT and laser generations since competitors machines were not compatible. If customers wanted the true Helvetica, then they had to go to Mergenthaler Linotype. Once more, however, incumbents did not maintain upward compatibility in the shifts to CRT typesetting and laser imagesetting. So, unless a customer required a particular typeface, the cost of switching vendors when switching generations was minimal.

5.3.4 Fifth generation: laser Postscript imagesetters

Almost every barrier to entry decreased with the emergence of Postscript. Most significantly, Postscript established an open digital font standard, and new entrants no longer needed to develop a font library in order to compete in the typesetter market. I therefore classify Postscript as "destroying" other barriers to entry.

Minimum Efficient Scale

While manufacturing scale had not been a significant barrier in the prior generation, Postscript standardized interfaces making entry possible simply by serving as a systems integrator. An entrant could OEM a laser recorder from one firm and a Postscript RIP (raster image processor) from another firm, knowing that the two would work together. Manufacturing scale was therefore no longer even an issue for entrants.

Sunk cost investment in font library

The most significant effect of Postscript was to make the method of encoding fonts standard across the industry. As discussed earlier, in prior generations, each firm had its own standards, and fonts from one manufacturer could not be used on the machines of another. New entrants therefore had to develop and encode their own font library - an effort which required substantial investment. With Postscript, not only were the fonts of incumbents available for use on new entrants' machines, but independent firms such as Adobe Systems could offer a compatible font library to the customers of new entrants. The emergence of Postscript as an industry standard therefore decreased barriers to entry significantly.

Reputation

While the growth of desktop publishing created new demand for imagesetting, most new users did not invest in purchasing an imagesetter. Instead, quick print shops such as the Kinko's chain grew to meet the increased demand for imagesetting. These firms were familiar with typesetting vendors, and reputation therefore continued to serve as a barrier to entry.

Compatibility

With standard Postscript fonts, customers could use the fonts of any manufacturer on any other manufacturer's machine. The switching cost associated with the need for a particular font was therefore eliminated.

In the movement from laser imagesetters to Postscript, most incumbents did maintain upward compatibility with their laser imagesetters. Compugraphic, for instance offered a machine that could incorporate both a

Postscript RIP and a proprietary Compugraphic RIP. If customers had invested in a proprietary Compugraphic font library, they could then continue to use those fonts on the Postscript machine. For firms that had already invested in a laser imagesetter, the cost of purchasing a Postscript machine was therefore lower if they bought from the same firm as opposed to from a new entrant.

5.4 Summary

Based on the preceding discussion, figure 5.4 summarizes the location of each generation of typesetter technology using the framework developed in Chapter Two. In the next section I examine descriptive data on the competitive dynamics in each cell of the matrix.

Figure 5.4

Effect of Typesetter generations on barriers to entry

Current Competence Destroyed?

	No	Yes
Yes	Digital CRT Phototypesetters Laser imagesetters	Analog phototypesetters
No	Hot metal typesetters	Laser Postscript imagesetters

Other Barriers to Entry Destroyed?

Chapter Six

Descriptive Data on Entry and Performance

6.1 Introduction

In Chapter Five I categorized each generation of typesetter technology in terms of its effect on current competence and on other barriers to entry. Using this framework, I now examine descriptive data about new entry and entrant/incumbent performance.

I first evaluate patterns of entry and market share shifts in each of the "boxes" of the framework. This data provides preliminary support of the hypotheses developed in Chapter Two. Incumbents appear to be buffered by other barriers to entry when they face competence-destroying technological change.

Next I reject two alternative hypotheses about why incumbent performance might differ in the transitions examined. I first demonstrate that incumbents, for the most part, did invest in each new generation of technology. Given that they invested, I then examine how their technical performance compared to that of new entrants. Using quantitative performance data, I find that for competence-destroying technologies, the initial development efforts of incumbents were inferior to those of new entrants. In order to get a better sense as to *why* incumbent performance was inferior, I then examine the development of the first analog phototypesetter by each of the incumbents as well as briefly discussing the first CRT machines developed by incumbents. I find that incumbents were handicapped in that the manner in which they approached new technology was shaped by their experiences in the prior generation.

Finally, I look at the characteristics of new entrants in each generation in order to understand what type of entrant perceived opportunities in the industry. I find that a potential entrant's perception of opportunity varies, depending upon the entrant's prior related experience. Firms with related technological experience were more likely to enter when only competence was destroyed (CRT and laser generations) whereas firms with related market knowledge were more likely to enter when both competence and other barriers to entry were destroyed (analog phototypesetter generation). In order to understand how a new entrant perceived an opportunity and took advantage of it, I explore the entry of one firm, AM Varityper, in depth.

6.2 Competitive dynamics: entry and market share

Using the classifications from Chapter Five, figure 6.1 displays the basic data on new entry and entrant market share for each technological generation.

Figure 6.1

New entry and Entrant market share by technological generation

Current Competence Destroyed?

	No	Yes
Yes	Digital CRT typesetters (CRT) • 14 new entrants • 16% new entrant share Laser imagesetters • 8 new entrants • 12% new entrant share	Analog phototypesetters (PTS) • 17 new entrants • 89% new entrant share
No	Hot Metal (HM) • 4 new entrants • 20% share	Laser Postscript Imagesetters • 7 new entrants • 20% new entrant share (estimate)

Other Barriers to Entry Destroyed?

New entrants are defined as firms that first enter the industry with a product in the given generation. For the hot metal generation, I examine entry between 1903, (when the linecaster architecture first clearly dominates with over 50% of market) and 1970 (when production of hot metal machines in the US ceases). For all other generations, I begin counting entry with the first new entrant. Market share is cumulative for the entire generation. For instance, of all CRT machines sold, 16% were sold by the 14 firms new to the industry in that generation

Given the hypotheses developed in Chapter Two, I expect to find the least new entry (and new entrant share) when both current competence and other barriers to entry are destroyed, and the most new entry (and new entrant share) when neither is destroyed. In terms of the generations of typesetter technology, I therefore expect the following:

HM < CRT ? Laser ? Postscript < Analog PTS

As can be seen from the new entry and entrant market share numbers below, I find that the hypotheses developed in Chapter Two are partially confirmed. When both current competence and other barriers to entry were destroyed in the analog phototypesetter generation, 17 new entrants captured 89% share of the generation, devastating incumbents. At the opposite extreme, during the hot metal era there is the least new entry, but entrants capture 20% of the market, more than in the CRT or laser generations. These numbers, however, may overstate entrant success. One firm, Intertype, entered in 1911, taking advantage of the expiration of key Mergenthaler patents and eventually capturing 20% of the market. There was absolutely no new entry between 1913 and 1970.

	HM	**<**	**CRT ?**	**Laser ?**	**Postscript**	**<**	**Analog PTS**
Entry	4	<	14	8	7	<	17
Share	20%	<	16%	12%	20% (est.)	<	89%

When the effect on current competence and other barriers differs, the performance of incumbents vs. new entrants will depend upon the strength of the two effects. Despite the destruction of incumbents' current competence by the CRT and laser generations, other barriers to entry remained, possibly protecting incumbents from the effects of competence destruction. It is also possible, however, that the effect of competence destruction was so strong that it overwhelmed the effect of other barriers to entry. The descriptive data presented above support the first effect. While I observe a significant number of new entrants, 14 in the CRT and 8 in the laser generations, new entrants did not capture a large portion of the market -- only 16% and 12% respectively of CRT and laser unit sales. New entrants perceived an opportunity due to the changing technology, but other barriers to entry, particularly the need for a font library, appear to have protected the incumbents from competition.

In the reverse case, when current competence is not destroyed, but other barriers to entry are, the result will again depend upon the strength of the two effects. As of 1990, the effects of Postscript on the typesetter industry were still being played out. There had been 7 new entrants, and industry experts estimated that they had gained about a 20% share of the market. There is much more price competition with this generation since products are more difficult to differentiate, so the industry may experience yet another shakeout.

6.3 Rejecting alternative hypotheses

The descriptive data above indicate that incumbents are at a disadvantage when both current competence and other barriers to entry are destroyed, but that they can survive competence-destroying technological change when protected by other barriers to entry. In this section I rule out two alternative explanations for this result.

First, it is possible that incumbents were at a disadvantage in the analog phototypesetter generation, as opposed to the CRT and laser generations because they failed to invest in it, but did invest in the others. I show that this is not the case. Second, it is possible that incumbents were successful in the CRT and laser generations not because they were protected by other barriers to entry, but simply because they acquired new capabilities quickly and developed superior products. One might also argue that I have overstated the nature of competence destruction, and these changes were not difficult for firms to make after all. If either of these arguments is true, then there should be no significant difference between the technical performance of products developed by incumbents and those developed by new entrants. I demonstrate that there is, in fact a difference. Finally, in order to understand the source of this difference, I examine a subset of incumbent development projects in depth.

6.3.1 Incumbent investment

As seen in Table 6.1 almost every firm that established even a moderate presence in a given typesetter generation (at least a 2% market share) invested in developing a machine for the following generation. In addition, while absolute numbers on the amount invested in new technology are not available, qualitative data from interviews with both management and development engineers indicate that the level of investment by incumbents was not substantially different from that of new entrants. One can therefore rule out lack of investment as the reason for incumbent failure in the analog phototypesetter generation.

Table 6.1

Incumbent Investment Responses

Generation	Number of Incumbents from prior generation*	Number of Incumbent Entrants	Percent of Incumbents that Entered
Analog Phototypesetters	3	3	100%
Digital CRT Phototypesetters	11	10	91%
Laser Imagesetters	11	9	82%
Laser Postscript Imagesetters	11	11	100%

* the number of incumbents that were a) alive when this generation began, and b) were successful enough in the prior generation to get at least a 2% share of the market in one year.

6.3.2 Technical performance: quantitative analysis

Given that incumbents invested in competence-destroying technologies, I next examine their technical performance. As discussed above, I am able to reject the hypothesis that incumbents in the CRT and laser generations were successful because of superior technical performance. I begin by comparing the technical performance of the first products developed by incumbents and new entrants in each generation.

As a measure of technical performance I use product speed. While many criteria are important to typesetter buyers, speed is the one criteria valued highly by all segments, and in interviews product development engineers it was consistently identified as a primary goal. The partial correlation coefficient of speed and price controlling for a number of other product characteristics, is 0.69. In addition, speed has also been used as the primary indicator of technical progress in technology forecasting studies of the typesetter industry (Mohn, 1971).

Table 6.2 compares the average speed and the year of introduction of the first phototypesetter made by incumbents as opposed to new entrants. For the analog phototypesetter generation two comparisons are made. The initial comparison considers the "imitation hot metal" machines made by Intertype and Monotype as first products. In this case the new entrants' machines were about three times as fast as the incumbents' machines, and the difference is statistically significant. The new entrants' machines were also introduced significantly later than the incumbents' machines. I therefore do another comparison in which the second machines introduced by Intertype and Monotype are substituted for the imitation hot metal machines, making the difference between average dates of introduction only 4 years. The speed of the new entrants' machines is still more than twice than that of the incumbent's machines, although the difference is not statistically significant. The small sample size however (only 3 incumbent machines) results in little statistical power.

Table 6.2

Incumbent vs. New Entrant Machine Speed (newspaper lines per minute) - Average of First Machines by Generation (Pairwise two-tailed t-test)

Technological Generation	Incumbent Machine	New Entrant Machine	Significance
Analog Phototypesetters*			
speed	14	41	p <.10
year introduced	1955	1967	p <.05
Analog Phototypesetters**			
speed	19	41	ns
year introduced	1963	1967	ns
Digital CRT Phototypesetters			
speed	399	974	p <.05
year introduced	1975	1973	ns
Laser Imagesetters			
speed	381	648	p <.10
year introduced	1983	1984	ns

* Includes Intertype Fotosetter (1949) and Monophoto Mark 2 (1956) as "first" incumbent machines
** Includes Intertype Fototronic 480 (1964) and Monophoto Mark 3 (1965)as "first" incumbent machines

In the CRT generation, new entrants' first machines were significantly faster than those of incumbents despite being introduced on average 2 years earlier. Likewise, in the laser generation, new entrant first machines were faster than incumbent machines with no significant difference between the years of introduction. Thus in all three competence-destroying generations I find the expected result: from a technical perspective new entrants initially outperform incumbents. I can thus rule out initially superior technical performance as the reason for incumbent success in the CRT and laser generations.

As incumbents gain experience in a generation, however, one would expect their technical performance to eventually come close to, if not match that of new entrants. I therefore compare the speed of incumbent and new entrant machines subsequent to the first machine announced. Due to a lack of data availability for the laser generation, I only perform this analysis for the analog and CRT generations. The results are shown in Table 6.3

Table 6.3
Incumbent vs. New Entrant Machine Speed (newspaper lines per minute) - Average of Subsequent Machines by Generation
(Pairwise two-tailed t-test)

Technological Generation	Incumbent Machine	New Entrant Machine	Significance
Analog Phototypesetters*			
speed	26	33	ns
year introduced	1970	1973	ns
Digital CRT Phototypesetters			
speed	547	1583	p <.05
year introduced	1980	1975	p <.01

* Intertype Fotosetter (1949) and Monophoto Mark 2 (1956) counted as "first" incumbent machines and the Intertype Fototronic 480 (1964) and Monophoto Mark 3 (1965)as subsequent incumbent machines

For the analog phototypesetter generation, incumbent firms eventually matched the technical performance of new entrants - there is no longer a significant difference between the speed of incumbent and new entrant machines. For the CRT generation, however, new entrants continued to hold a strong lead, with an average speed almost three times that of incumbents despite the fact that their machines were introduced significantly earlier than incumbent machines. It appears that catching up technologically was more difficult for incumbents in the CRT generation than in the analog phototypesetter generation. Despite this difference, incumbent firms performed better in the CRT generation than in the analog phototypesetter generation. Once more, superior technical performance is not responsible for incumbent success.

6.3.3 Technical performance: qualitative analysis

While the preceding numbers clearly establish that incumbent machines did not perform as well in competence-destroying generations, it is useful to look in depth at a few examples in order to understand how incumbents were handicapped by their prior experience. In the following section I examine the development of each hot metal incumbent's first analog phototypesetter. I then briefly examine the first CRT machines of analog phototypesetter incumbents

In each of these cases, existing capabilities shaped the manner in which incumbents approached the new technology. Given that these organizations had strongly established, efficient routines embedded in the architecture of the prior generation, their natural inclination was to utilize those same routines in the development of the following generation's machines. The first phototypesetter developed by each of the hot metal firms was thus based on its hot metal architecture. Likewise, the first CRT machines of incumbents utilized elements of analog phototypesetters. While technically disappointing relative to the machines of new entrants, these machines may have represented the best effort possible by the incumbents at the time.[1]

Intertype

Intertype began work on a phototypesetter in 1936 after the firm's president, Neal Dow Becker was approached about the idea of a modified hot metal machine during a European business trip. He assigned Herman Fruend, the hot metal chief engineer, with the task of developing such a machine. Fruend worked on the project with a team of mechanical engineers from the hot metal organization. Since the group had little expertise in optics and lenses, they

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[1] There is a trade off between utilizing existing competencies which are efficient, but may not be entirely appropriate as opposed to developing new, appropriate capabilities which are not yet efficient. How firms should analyze this trade-off is an interesting question for future research.

involved Eastman Kodak in the design of the lens component of the machine. Kodak also developed special film to work with it.

After 10 years of development effort, a prototype was ready to be field tested. It was installed at the US Government Printing Office in Washington in 1946. The machine was essentially a modified hot metal linecaster (see figure 6.2). The basic architecture was the same, except the casting unit had been replaced by a photo unit. The machine used circulating matrices which had a film image of a letter embedded in them instead of an imprint of a letter (see figure 6.3). Matrices were photographed one at a time, with the film carriage advancing between letters. The amount of escapement of the film carriage was mechanically based on the width of the matrix (see figure 6.4).

Commercial models of the machine, called the Fotosetter, began shipping in 1949. Sales were initially slow, with a handful of machines shipping each year as design and production problems were worked out. By 1954, Intertype reported revenues of over half a million dollars from the sale of Fotosetters - about 15 machines, and by 1956 that number had risen to almost a million dollars. After 1956, however, when competitive machines reached the marketplace, sales of the Fotosetter stabilized. By 1961, Intertype's share of the phototypesetter market had fallen from 100% to only 12%. Clearly new entrants were capturing the growth in the market.

Figure 6.2

Intertype Fotosetter

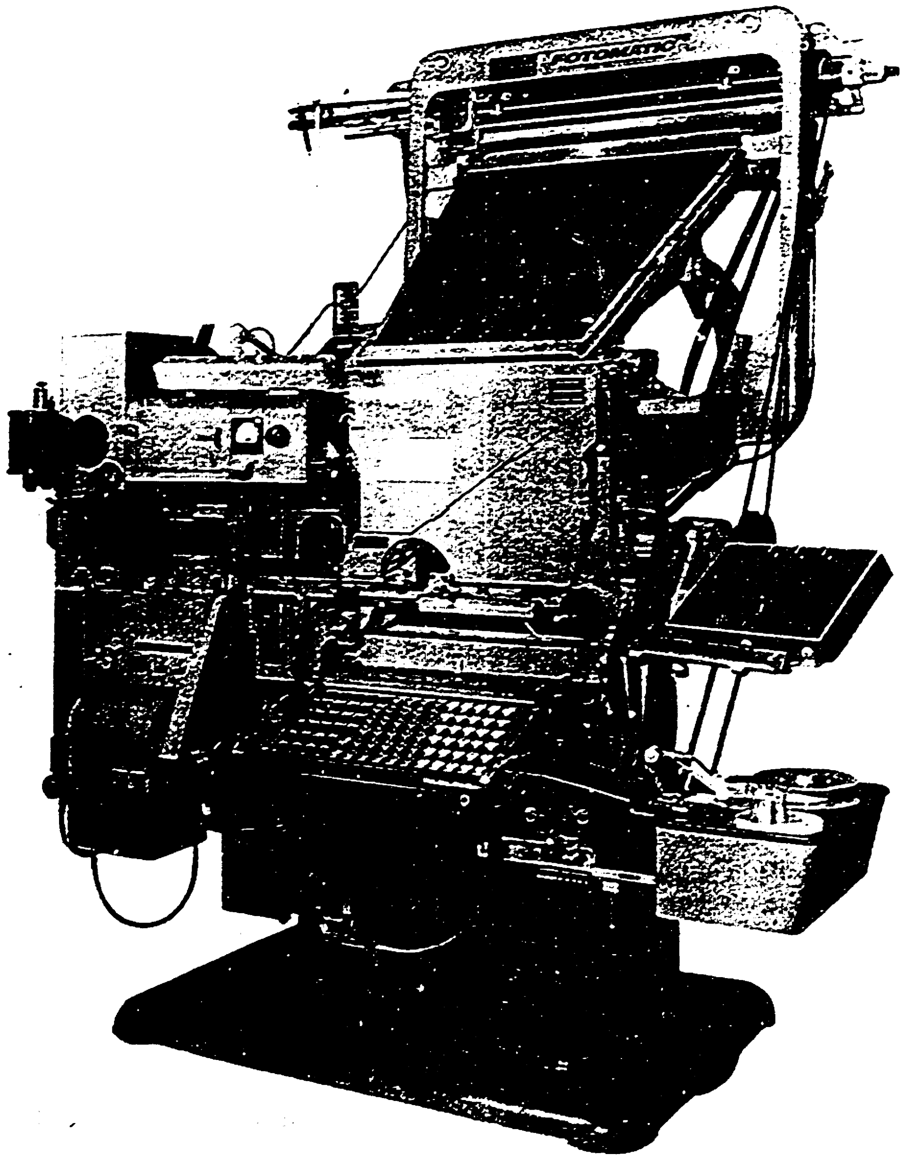
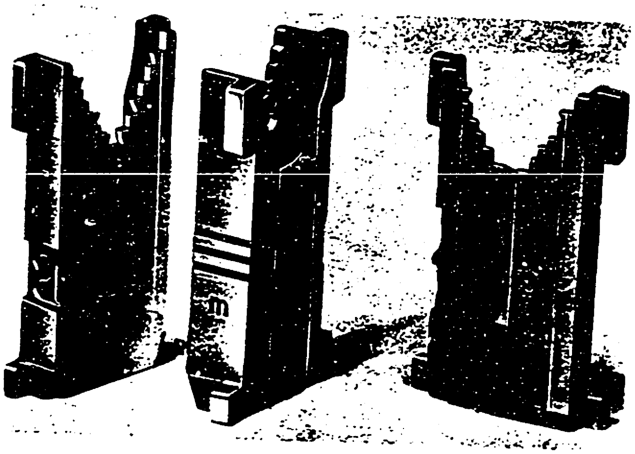


Figure 6.3

Hot Metal vs. Intertype Fotosetter Matrices

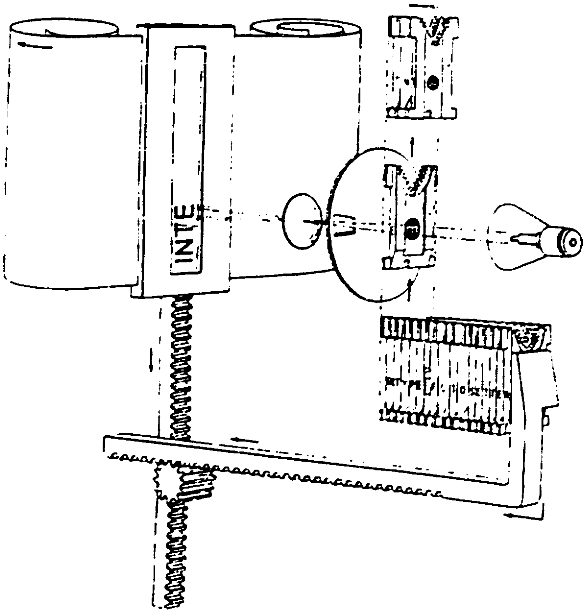


Hot Metal

Fotosetter

Figure 6.4

Intertype Fotosetter Optical System



Monotype

Monotype also had the opportunity to become involved in photocomposition at an early stage. An engineer with a continuing interest in design, George Westover, the London Manager commenced research on a phototypesetter in the early 1930's without the official sanctioning of the corporation. The design developed by Westover utilized many of the concepts embodied in the hot metal Monotype machine. For instance, characters were stored on a photo-matrix grid shaped and manipulated like the matrix case of a hot metal machine. Patents on the machine, called the Rotofoto, date from 1936. Despite Westover's efforts to interest Monotype management in his invention, the corporation was officially not interested in phototypesetting. As one ex-Monotype employee stated, "His perspicacity was not appreciated in more conservative quarters and his efforts encountered a great deal of skepticism, inertia, and even some obstructionism...The Monotype Corporation refused to show any interest in the Rotofoto system or of bestowing any financial patronage" (Wallis, 1993 p.19). Westover resigned from the firm shortly after the advent of World War II and attempted unsuccessfully to commercialize the Rotofoto.

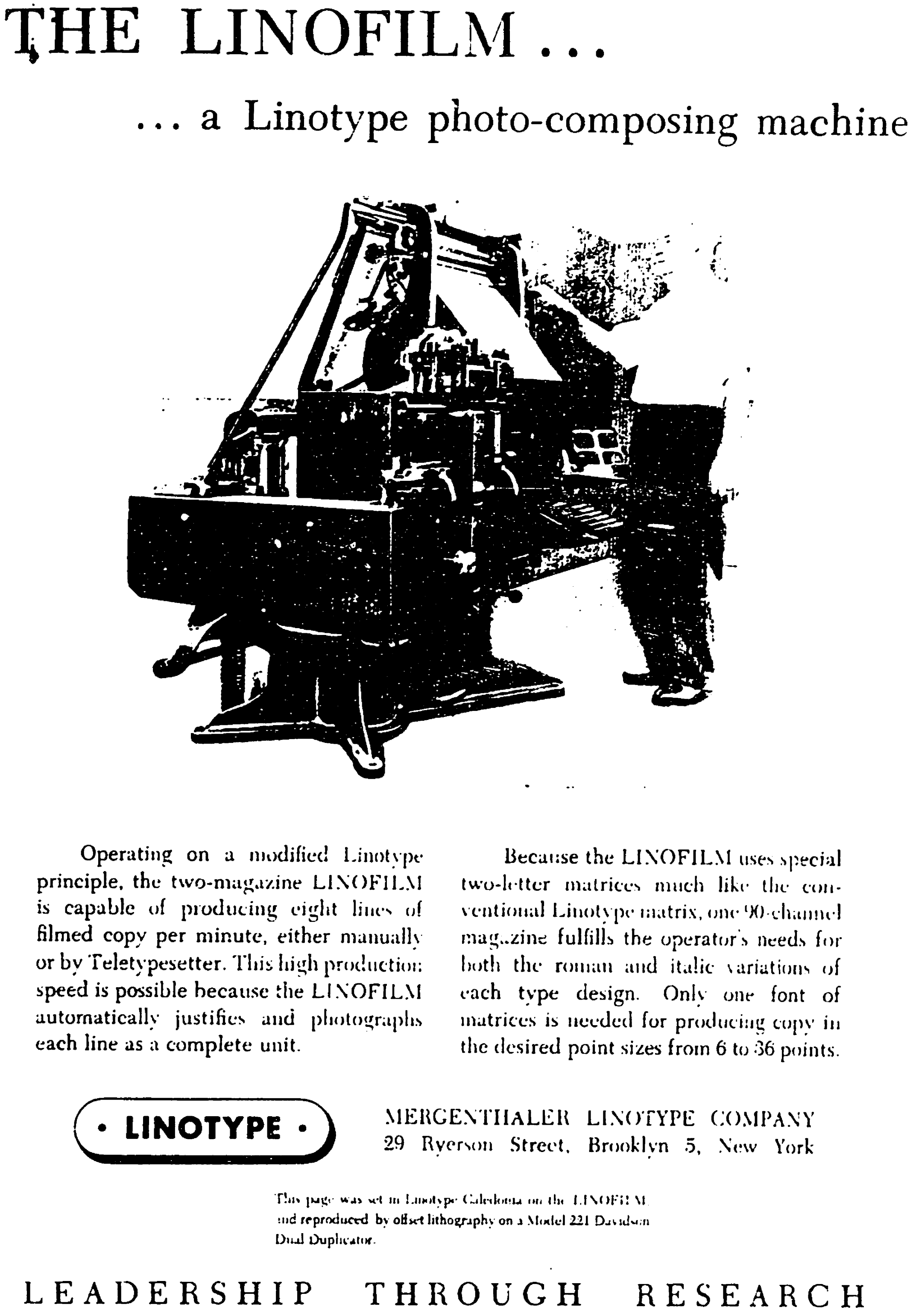
After World War II, a project to develop a commercial phototypesetter was formally initiated. This project was staffed by the same engineering staff responsible for hot metal development, and the resulting Monophoto bore a great deal of resemblance to the Rotofoto. The machine used the same keyboard input as a traditional hot metal Monotype and produced a 31 channel paper tape. A solid glass grid with film images of characters replaced the matrix case. As with the hot metal machine, the grid was moved mechanically to select a character. Rather than cast metal into a mold, however, the selected character was positioned over a flash and exposed onto film. The 1952 *Penrose Annual* quoted E. Silcock, general manager of the Monotype Corporation as optimistically stating the Monophoto "had emerged from years of testing and development to the level where it can now be placed into commercial operation." The development, however, dragged on for another five years as the team attempted to match the capabilities of the hot metal machine. Most importantly, users of hot metal Monotypes were accustomed to being able to change individual characters in the matrix case as desired. With a solid glass grid this was not possible. The machine was therefore redesigned, substituting for the glass grid with a matrix case which held individual film characters that could be interchanged. The machine was not actually installed commercially until 1957. It ran at the same speed as a hot metal Monotype, and only one size could be set at a time. By 1959 only 5 - 10 machines had been placed.

Mergenthaler Linotype

Mergenthaler began work on a phototypesetter in about 1948, much later than the other two incumbents. The initial project was led by hot metal engineers and the design was based on the Friedman-Bloom patent of 1926. This machine, like the Fotosetter and Monophoto, was based on hot metal architecture. It used recirculating matrices which had a painted image of a character on the matrix where the impression of the character would have been etched on a hot metal matrix. When a line of matrices had been composed from the keyboard, it was moved over to the modified "casting unit" where a picture of the completed line was taken. The machine, called the Linofilm, was exhibited at a trade show in Chicago in 1950. Figure 6.5 is a copy of product literature distributed at that show. An internal corporate newsletter dated October of that year stated, "The Comet, the ML Quadder [hot metal developments] and the Linofilm were ready in time for the International Graphic Arts Exposition in Chicago in September... Linotype with its three research developments, was widely heralded as the hit of the show." Despite this apparent enthusiasm, Mergenthaler management decided not to continue development of the machine based on extremely negative input from the sales organization, and the project was abandoned.

Figure 6.5

Original Mergenthaler Linofilm Trade Show Flyer (1950)



THE LINOFILM ...

... a Linotype photo-composing machine

Operating on a modified Linotype principle, the two-magazine LINOFILM is capable of producing eight lines of filmed copy per minute, either manually or by Teletypesetter. This high production speed is possible because the LINOFILM automatically justifies and photographs each line as a complete unit.

Because the LINOFILM uses special two-letter matrices much like the conventional Linotype matrix, one 90-channel magazine fulfills the operator's needs for both the roman and italic variations of each type design. Only one font of matrices is needed for producing copy in the desired point sizes from 6 to 36 points.

• LINOTYPE •

MERGENTHALER LINOTYPE COMPANY
29 Ryerson Street, Brooklyn 5, New York

This page was set in Linotype Caledonia on the LINOFILM and reproduced by offset lithography on a Model 221 Davidson Dual Duplicator.

LEADERSHIP THROUGH RESEARCH

Incumbents' performance in the CRT generation

Like the efforts of hot metal firms, the development efforts of analog phototypesetter firms were also shaped by prior technological experience. The first CRT machines developed by many incumbents continued to store letters as analog film images, the way they had been stored in the prior generation. In contrast, new entrants such as Alphanumeric and Hell stored letters as digital information on a tape or magnetic disk. Since incumbents had experience in manipulating the film images, they felt more comfortable continuing to utilize that technology.

Incumbent Compugraphic's first CRT machine, the Videosetter used a film grid to store characters. In addition, character width data was also stored optically on the grid. As a Videosetter development engineer stated in an interview (1994), "We didn't know anything about magnetic storage of digital data. It was easier to just continue using film." Mergenthaler Linotype's first CRT machine, the Linotron 1010 announced in 1967, and Crossfield's Magnaset, announced in 1971, also used photographic grids. Some dominant firms from the analog phototypesetter generation, Itek and AM Varityper did enter the CRT generation with digital machines, but they entered quite late -- in 1979 and 1981 respectively.

6.4 New entrants

It is clear from the descriptive data that incumbent firms were at a technological disadvantage relative to new entrants in the industry. And when other barriers to entry were destroyed, they lost significant market share. What type of new entrants, however, perceived that the destruction of technological competence and/or other barriers to entry created an opportunity? Did the same type of firms enter at each technological discontinuity? In addition, what factors enabled particular entrants to be successful? This section provides preliminary answers to these questions. It first examines the type of entrants in each technological generation and then looks in depth at the characteristics and entry strategy of one successful new entrant, AM Varityper.

6.4.1 New entrant characteristics

Table 6.4 summarizes the background of the new entrants in each generation (details about individual new entrants, their background, and related skills are found in Appendix C). Diversifying firms are classified as having either related market experience, related technical experience or both (there was no unrelated diversification into typesetting). Participants in other parts of the broader graphic arts industry were considered to have related market experience. This included, for instance, manufacturers of printers, printing and typesetting supplies, image scanners, justifying typewriters, and type foundries as well as typesetter users such as service bureaus. Related technical experience varied by technological generation, and was based upon the relevant skills for each generation listed in Chapter Five (figure 5.2). Firms were classified as de novo even if the founders had previously worked for another typesetter manufacturer.

Table 6.4

Typesetter new entrant characteristics by technological generation

Technological Generation	Total Number of New Entrants	Diversifying with only related market knowledge	Diversifying with only related technical knowledge	Diversifying with both related market and related technical knowledge	De Novo
Analog Phototypesetters	17	**41%**	6%	**47%**	6%
Digital CRT Phototypesetters	14	14%	**36%**	**36%**	14%
Laser Imagesetters	8	12.5%	**37.5%**	**50%**	0
Laser Postscript Imagesetters	7	28.5%	0	28.5%	43%

Several interesting patterns emerge regarding what type of firms perceived entry opportunities in different generations. Related market knowledge was clearly a driver of entry in the shift from hot metal to analog phototypesetting, with 88% of new entrants possessing such knowledge. After over 50 years of watching the hot metal competitors make money in an oligopolistic industry, these firms were poised to take advantage of the new technology. They were in a position to recognize that both current competence and other barriers to entry were destroyed, and clearly perceived the vulnerability of the incumbents.

When the technology shifted to CRT typesetters, we find a very different type of entrant. In this case, the majority of the entrants had related technical knowledge (71%). These firms saw that they had a technological advantage over incumbents given the competence-destroying nature of CRT technology, and therefore perceived an entry opportunity. Half of the entrants with related technical expertise, however, lacked related market expertise. Without an understanding of the market these entrants may have underestimated the strength of other barriers to entry in the industry, such as a font library. As discussed above, despite the high number of entrants in the CRT generation, they captured very little market share.

A similar pattern is seen for the laser imagesetter generation. The majority of the entrants had related technical knowledge (88%) but many of those were lacking related market knowledge. Once more, firms recognized the opportunity to use their technological expertise, but underestimated the strength of other barriers to entry.

In the final, Postscript generation, it is interesting to note that none of the diversifying entrants had related technical knowledge without related market knowledge. Since the shift did not destroy the technological competence of incumbents, potential entrants with only strong technology did not perceive an advantage over incumbents. The shift to Postscript did destroy other barriers to entry, and for the first time we see a large percentage of de novo entrants (43%). It appears that in the previous generations, potential de novo entrants felt that they were at a disadvantage relative to diversifying entrants and decided not to enter. In this generation, the standard interfaces generated by Postscript made it easy for new entrants to enter as systems integrators, using components from others. These entrants, however, may have underestimated the technological competence necessary to compete, and so far have not done very well against incumbents.

6.4.2 An example of successful entry: AM Varityper

One of the more successful new entrants to the analog phototypesetter generation was AM Varityper, a subsidiary of AM (Addressograph-Multigraph), a diversified conglomerate. Varityper captured 28% of the unit share of the analog phototypesetter generation. In this section, I briefly describe why Varityper perceived an entry opportunity in the typesetter industry, and how they were successful in pursuing that opportunity.

As a corporation, AM had a great deal of related market experience in the graphic arts. The Varityper division sold justifying typewriters; the Multigraph division sold offset duplicators; the Bruning division sold copiers and diazo printers, and the Buckeye division sold printing supplies.[2] The firm had a strong presence in corporate offices where Varityper justifying typewriters were used in conjunction with Multigraph offset duplicators, allowing for an inexpensive in-house publishing operation.

The commercialization of phototypesetters provided an attractive option for these customers if they were interested in upgrading to produce higher quality internal publications. Phototypesetters were less expensive than hot metal typesetters and, lacking a pot of molten lead, were much better suited to an office environment. AM recognized the threat of substitution for its existing business, and the firm therefore evaluated the feasibility of entry into the typesetter market.

Despite its own lack of relevant technological expertise, the firm perceived an opportunity created by the changing technology. Hot metal incumbents did not have any established reputation with "in-house" customers and were also lacking a sales presence in that segment of the market. Varityper had both a good reputation and a strong sales presence. Varityper already had a moderate font library since it offered a variety of fonts for use in its justifying typewriters. The hot metal firm font libraries were therefore less of a barrier. In addition, the firm also clearly understood the need to invest in additional fonts and to signal to buyers that fonts were a high priority. The only thing the firm lacked was technology, and management felt that the Varityper division was in just as good

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[2] Other divisions included Addressograph, which sold business tabulating / data processing systems and Emeloid, which sold custom plastics

a position as the hot metal typesetter firms to acquire the required technological expertise. In about 1965 AM Varityper therefore explicitly set out to acquire expertise in analog phototypesetting technology from the clear technology leader, Photon.

While not as simple as management had originally anticipated, the organization was able to develop internal expertise in analog phototypesetter design and manufacture. AM Varityper's first machine, the AM 725 in 1969, was designed and manufactured by Photon. Given the strength of Varityper's sales organization the machine did moderately well, selling about 100 units a year, and three more models were announced in 1970 and 1971 with similar results. Although management's goal for the relationship with Photon had been to acquire technological expertise, very little technology was ever explicitly transferred. "No technical people from Photon ever visited Varityper, and we were not allowed to visit Photon." stated one Varityper engineer in an interview. Varityper did, however, have the right to make incremental changes to the Photon machine under its contract, so internal engineers began experimenting. In 1971, an electrical engineer was hired to head up the R&D organization, and emphasis was given to phototypesetter development. Announced in 1972, the first internally developed product, the AM 748 was a low cost version of the Photon machine. While moderately successful, the machine was in no way a "home run." It did, however, give the development organization experience in phototypesetter development. Work on a totally home-grown machine had begun in late 1971, and this time the result was a huge success. The Comp/Set 500, announced in 1974, was the first direct entry machine with a full size video screen for text input and editing.[3] It was also relatively low cost and targeted at

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[3] Interestingly, the lead engineer on the Comp/Set 500 was a mechanical engineer that had previously worked on the design of justifying typewriters. When the focus of the organization shifted to electronics and opto-mechanical engineering, this individual spent some time at different universities (e.g. MIT) retraining. How a firm should handle human resources, and the trade-off between retraining existing employees as opposed to hiring all new employees is an interesting agenda item for future research.

the in-plant segment where AM Varityper was strong. Over 11,000 Comp/Sets were sold over the life of the product.

In summary, as a result of its market knowledge, AM Varityper was able to recognize the opportunity created by analog phototypesetter technology, and to attack a new market segment. The firm was clearly in a good position to take advantage of the technology from a marketing standpoint, and given the perception of a technological lag on the part of incumbents, decided to also invest in developing its own technological expertise. Varityper was successful in developing technological expertise, and that combined with its prior market strength enabled it to successfully enter the typesetter market.

6.5 Summary

This chapter has examined descriptive data about incumbent and new entrant performance in each technological generation of the typesetter industry. Based on a simple examination of new entry and entrant market share, support for the hypotheses developed in Chapter Two is found. New entrants were most successful when both current competence and other barriers to entry were destroyed. Incumbents in this situation were shown to invest in the new technology, but develop technologically inferior products. New entrants, a majority of which had related market expertise, were successful in capturing most of the market.

I also find evidence that other barriers to entry can protect incumbents from the effects of competence destruction. Despite a number of new entrants in the CRT and laser generations, incumbents maintained a high market share. A comparison of the technical performance of incumbent and new entrant products shows that this success was not a result of superior technical performance. The incumbent's products were technically inferior, yet the firms still performed well, implying that they were, in fact, buffered by other barriers. Most of the new entrants in the CRT and laser generations had related technological expertise, but many were lacking any related market expertise. These firms perceived an opportunity created by new technology, but most likely underestimated the strength of other barriers to entry given their lack of market knowledge.

Finally, qualitative data was used to identify the source of the incumbent's technical disadvantage Incumbents were found to be handicapped by their prior experience in that this experience shaped their response to the new technology; they attempted to use the architecture and skills of the prior generation in developing products for the new generation. New entrants, however, unencumbered by prior experience, were found to be more open to diverse approaches. In the next chapter I use more sophisticated quantitative methods to examine the effect of technological change on entry and performance.

Chapter Seven

Quantitative Analysis of Entry and Performance

7.1 Introduction

In Chapter Five, I described how technological change in the typesetter industry affected both the competence of incumbent firms as well as other barriers to entry. I then provided qualitative evidence and descriptive data regarding how those shifts affected the performance of incumbents and new entrants to the industry. Despite the fact that the CRT and laser generations were competence destroying, established firms performed quite well. This result is in contrast to the analog phototypesetter generation where incumbent firms performed poorly in the face of competence destroying technological change. The difference between the effect of these generations is attributed to the difference in the way other barriers to entry were affected by the technological change. In this chapter I use quantitative methods to further explore the intuition developed in Chapter Six.

I first examine entry patterns for each generation of technology. From the descriptive statistics it is not clear that entry in the second analog phototypesetter generation, where both current competence and other barriers to entry decreased, was that much different from entry in the CRT, laser, or laser Postscript generations. Examining the raw number of entrants also does not control for factors such as the growth rate and size of the technological segment or the number of other competitors already in the segment. I therefore model entry into a generation as a function of both barriers to entry and these other factors. I demonstrate that be examining only the destruction of current competence destruction and ignoring other barriers, one may get misleading results.

Simply modeling the amount of entry ignores a critical element -- the performance of new entrants. I therefore next examine the market share of incumbents vs. new entrants when faced with competence-destroying technological change. While the aggregate data in Chapter Six showed that incumbent firms lost significant market share in the analog phototypesetter generation but not in the CRT or laser generation, it once more does not control for the growth of the technological segment, the number of competitive products in the market or the price of the product. Controlling for these factors, I examine the effect of incumbency -- a firm's experience in the prior generation -- on performance in the current generation. I find that when incumbents are protected by other barriers to entry, as in the CRT and laser generations, prior experience is not a handicap, and the effects of competence destruction on market share are not significant. Only when both other barriers to entry and current competence are destroyed is an incumbent's prior experience a liability, and incumbent market share in these cases is significantly lower.

7.2 Modeling entry

7.2.1 The model

I begin the analysis by examining rates of new entry into each generation of technology. My goal is to understand the effect of both competence destruction and other barrier destruction on the amount of new entry into a technological generation. I compare separate models of competence destruction and other barrier destruction with a model which includes measures of both in order to demonstrate the importance of considering both perspectives. I perform this analysis first using dummy variables and then richer measures to represent competence destruction and other barrier destruction. I then test one of the hypotheses developed in Chapter Two:

$$E_{ee} < E_{ed} \ ? \ E_{de} < E_{dd}$$

where E stands for new entry, e for enhance and d for destroy. The first subscript represents the effect of a technological generation on current competence and the second, the effect on other barriers to entry. Controlling for other factors, I examine whether entry is greatest in the phototypesetter generation, where both competence and other barriers to entry are destroyed. I also test whether entry in the CRT, laser and laser Postscript generations is greater than in the stable Hot Metal era.

As is standard, I assume that entry is governed by a Poisson process (Hannan & Freeman, 1989; Ranger-Moore, et al., 1991; Scott-Morton, 1994).

I employ the usual Poisson specification[1] where $E(N_i \mid X_i) = \lambda$.

λ is parameterized as follows:

$$\lambda = \exp(b_0 + b_i X_i)$$

where X_i is a vector of variables including competence-based barriers to entry, other barriers to entry, and controls.

7.2.2 Measures

The dependent variable

New Entry

I measure entry separately for each of the five generations of technology. I start with the first year a product was delivered in a given generation, and count the number of new entrants in that generation each subsequent year until the year in which the last product announcement for that generation occurs. Entry into the industry is measured by technological generation as opposed to simply a single count for the industry as a whole in order to distinguish between the characteristics of each generation. Since there is substantial overlap between generations of technology, a firm contemplating entry must choose, not only whether to enter, but which generation of technology to enter. By examining each generation of technology separately, I better capture the factors driving this decision process.

New entrants can be de novo firms, diversifying firms entering greenfield, or diversifying firms entering via acquisition of an existing player. Of a total of 46 firms which entered the industry during the period under examination, 6 were de novo entrants, 37 were diversifying entrants entering greenfield, and 3 entered via acquisition. I do not count incumbent firms entering the next

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[1] A standard assumption of the Poisson model is that the expected number of events in a unit interval and the variance of the number of event are equal. If this is not the case, overdispersion results in underestimation of standard errors, and thus overestimation of significance levels. I test for overdispersion as proposed by Cameron & Trivedi (1990) - testing for the significance of the coefficient in a regression of z = ((y-m)^2)-y)/(sqrt2*m) on w=m^2/(sqrt 2 *m), where y is the actual value and m the predicted value from the Poisson model. The test shows no evidence of overdispersion since the coefficient is not significant.

generation of technology as entrants since I want to capture only new entry to the industry. I do however control for incumbent entry as discussed below.

Control variables

Density

Density is measured as the number of firms competing in the technological generation at the beginning of each year. Prior work has shown that density generally has a positive first-order effect, and a negative second-order effect on entry implying an inverted-U shape relationship (e.g. Hannan & Freeman, 1977, Hannan & Freeman, 1989; Ranger-Moore et.al., 1991). The explanation given for this relationship is the combination of two effects: legitimation and competition. Initially as firms enter the industry, they serve to legitimize entry for other firms. Eventually, however, the competitive effect of additional firms outweighs the legitimation effect, and one finds entry rates decreasing.

Incumbent entrants

Incumbent entrants is measured as the cumulative number of firms from the prior generation than have entered the current generation. In addition to density the number of incumbent entrants may have an incremental effect on new entry. For the same reasons as with density, as more incumbents enter, one might initially expect more entry and eventually less entry. Alternatively, incumbents may be viewed as stronger competitors, and the effect of more incumbents on entry may simply be negative.

Growth

Growth each year is measured as the average unit growth in a technological generation for the prior three years. Since growth enables firms to enter the industry with less of a depressing effect on price, it is expected that growth will have a positive effect on entry (Orr, 1974).

Size

Size each year is measured as the number of units sold in each generation in the prior year. As with growth, size is expected to have a positive effect on entry.

Competence-based variables

Competence destruction dummy (CD)

If a generation destroyed competence relative to the prior generation, then the competence-destruction dummy is coded as one. The construction of the variable is based upon an in-depth examination of the industry and the technologies as discussed in Chapter Five (see Figure 5.2).

Skill Loss

The degree of competence-destruction imposed by a given generation is measured by skill loss, the percentage of skills from the prior generation which must be replaced in order to develop a product in the new generation of technology. The value of this variable is based upon an examination of the product development staffing records for a subset of firms in the industry and the details of its construction are also discussed in Chapter Five (see Figure 5.2).

While this measure may overestimate the degree of change needed since perhaps some engineers could be retrained, it also underestimates the degree of change needed by ignoring architectural changes to the product which may have proven difficult to master even if the skill set remained constant. The innovation literature would predict that the higher skill loss is the more entry one should expect. Once one also controls for the effect of other barriers, however, the expected sign is uncertain.

Other barriers to entry

Other barrier destruction dummy

If a technological generation destroyed other barriers relative to the prior generation, then this dummy is coded as one. The variable, then, does not represent the height of barriers in a particular generation, but the change from the previous generation. The construction is based upon an in-depth examination of the industry and the technologies as discussed in Chapter Five and summarized in Table 5.2 .

Minimum Efficient Scale

As in other studies (Caves, Porter & Spence, 1980; Montgomery & Hariharan, 1991) minimum efficient scale is measured as the average size of the largest plants, including plants which comprise at least half of output. This number is divided by total output. A separate measure of MES was made for each technological generation. These numbers were reviewed with manufacturing engineers in the industry for confirmation. As discussed earlier, the traditional barriers to entry literature would predict that the larger this ratio, the less entry one should see. Controlling for competence-based effects, however, the expected sign is unclear.

Summary of variables

Tables 7.1 and 7.2 summarize the variable definitions, measures, and descriptive statistics discussed above.

Table 7.1
Poisson Entry Model - Variables and Measures

Variable	Measure
NEW ENTRY	A count of all entrants in a technological generation in a given year that have not participated in the industry before
Measures of Competence-destruction	
COMPETENCE DESTROYING	Dummy variable set equal to one if the current generation was competence-destroying relative to the last generation
SKILL LOSS:	The percentage of the development team from the prior generation which must be replaced in order to develop a product for the current generation.
Measures of Other Barriers to Entry	
OTHER BARRIERS TO ENTRY DESTROYING	Dummy variable set equal to one if Other barriers to entry from the prior generation were destroyed by the current generation
MES	The average plant size of the largest plants (accounting for at least half of the output) divided by the total unit shipments in the generation of technology.
Controls	
SIZE	Number of units sold in the prior year for the given generation
GROWTH	Average unit historical growth for the prior 3 years for the given generation
DENSITY	The total number of firms participating in the generation at the beginning of the period
INCUMBENT ENTRANTS	The number of incumbents from the prior generation that have entered this generation as of the beginning of the period

Table 7.2
Poisson Entry Model Descriptive Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
NEW ENTRY	.32	.69	0	3
COMPETENCE DESTROYING	.55	.50	0	1
SKILL LOSS	.41	.39	0	.90
OTHER BTE DESTROYING	.30	.46	0	1
MES	.13	.13	.005	.30
SIZE	2554	3031	1	12000
GROWTH	.31	.49	-.52	1.97
DENSITY	6.58	4.35	0	18
INCUMBENT ENTRANTS	2.6	3.4	0	11

7.2.3 Results of modeling entry

Controls

Tables 7.3 and 7.4 contain the results of modeling entry. Consistent with prior work, the sign of the coefficient of DENSITY is positive and highly significant and that of DENSITY^2 negative and highly significant across almost all model specifications. This result is interesting in that most of the prior work examining "density dependence" has not taken into account the effect of barriers to entry. In that sense, this research provides additional support for existing work in this area. The number of incumbent entrants may have a mild incremental effect in addition to that of density. Its coefficient is negative and moderately significant in three of the seven specifications. This negative first order effect indicates a stronger competitive influence as opposed to a "legitimation" effect when incumbents enter.[2]

Two measures of demand, GROWTH and SIZE are included in the models. As expected, GROWTH has a positive effect on entry and is highly significant in six of the seven specifications. SIZE, however is insignificant in all specifications.

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[2] In specifications which included an (Incumbent Entrant)^2 term, it was not ever significant.

Table 7.3
Determinants of Entry
(with dummy variables for competence and other barrier destruction)
Poisson Regression

Dependent Variable = New Entry count, by technological generation, n=153

	Model 1	Model 2	Model 3	Model 4
CONSTANT	-3.38*** (.85)	-2.94*** (.72)	-3.35*** (.83)	-4.41*** (.88)
DENSITY	.22 (.16)	.40*** (.14)	.32* (.17)	.54*** (.17)
DENSITY ^{2}	-.009 (.009)	-.019** (.008)	-.015* (.009)	-.023*** (.009)
log (SIZE)	-.056 (.12)	-.084 (.09)	-.007 (.12)	-.064 (.12)
GROWTH	1.13*** (.26)	1.07*** (.25)	1.07*** (.26)	.44 (.31)
INCUMBENT ENTRANTS	-.062 (.070)	.010 (.068)	-.013 (.073)	-.23** (.100)
COMPETENCE DESTROYING	.80* (.46)		.48 (.48)	
OTHER BTE DESTROYING		.73** (.31)	.61* (.33)	
*COMPETENCE DESTROYING * OTHER BTE DESTROYING*				2.15*** (.62)
*COMPETENCE DESTROYING * OTHER BTE ENHANCING*				2.44*** (.76)
*COMPETENCE ENHANCING * OTHER BTE DESTROYING*				3.77*** (.96)
log likelihood	-102.3	-101.1	-100.6	-94.2

Standard errors in parentheses
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table 7.4
Determinants of Entry
(with continuous measures of competence and other barriers)
Poisson Regression

Dependent Variable = New entry count by technological generation, n=153

	Model 1	Model 2	Model 3
CONSTANT	-3.23*** (.81)	-1.75** (.70)	-1.47* (.99)
DENSITY	.23 (.16)	.31** (.14)	.35** (.15)
DENSITY ^{2}	-.010 (.008)	-.014* (.008)	-.016* (.008)
log (SIZE)	-.035 (.112)	.024 (.089)	-.001 (.010)
GROWTH	1.15*** (.26)	.76*** (.27)	.72*** (.28)
INCUMBENT ENTRANTS	-.035 (.066)	-.13* (.007)	-.14* (.007)
SKILL LOSS	.85* (.50)		-.36 (.58)
MES		-8.29*** (2.37)	-9.02*** (2.68)
log likelihood	-102.4	-96.2	-96.0

Standard errors in parentheses
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Distinguishing competence-based and other barriers to entry

I next attempt to distinguish between the effects of destroying current competence vs. destroying other barriers to entry. I first analyze the effect on entry using dummy variables to represent competence-destruction and other barrier destruction (Table 7.3). Model 1 examines the effect of competence-destruction on entry without controlling for other factors, as a traditional analysis in the innovation literature might. As this literature would predict, it appears as though competence-destruction has positive effect on entry, although it is only moderately significant (p<.10). In Model 2, I test for the effect of other barrier destruction on entry without controlling for the effects of competence destruction. As the traditional economic barrier to entry literature would predict, the coefficient of the other barrier destruction dummy is both positive and significant. I next include both competence-destruction and other barrier destruction dummies in order to examine the effect on each of controlling for the other (Model 3). While other barrier destruction continues to have a positive and significant effect on entry, the effect of competence-destruction is no longer significant. The significance of competence-destruction in Model 1 may therefore have been misleading. The competence-destruction point estimate, however, does not change substantially (0.48 in Model 3 vs. 0.80 in Model 1), indicating that I may simply may not have enough statistical power to observe the effect of competence-destruction in Model 3.

In Model 4 I test the relationships hypothesized earlier by comparing the effect on entry of each of the four "boxes" in Figure 2.2. I do so by creating an interaction term for each box. The omitted interaction is the case where both competence-based and other barriers are enhanced.[3] The least amount of entry is expected to occur in this case. I therefore expect to find the coefficients of the

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[3] The specification which includes dummy variables for the three interaction terms is identical to one which would include two main effect dummy variables and one interaction. This specification was chosen to facilitate the comparison of the interactions.

other three interaction terms to be positive. The most entry is hypothesized to occur in the case where both competence and other barriers are destroyed. I therefore also expect that interaction to have the largest coefficient.

The results in Model 4 confirm the first expectation: the coefficients of all three interactions are positive and significant, indicating that the least entry did occur in the case where both competence-based and other factors were enhanced. The second expectation, however is not confirmed. The coefficient of the interaction between competence destruction and other barrier destruction actually appears to be lower than the other two interactions, although it is not statistically significantly different from either of the other two interactions.[4] Since these dummy variables are capturing the effect of multiple factors without including any of the dimension associated with those factors, this result is not surprising. In addition, I simply may not have enough power to distinguish between the interactions since there are only nine observations that enhance competence and destroy other barriers. Including the interaction between competence destruction and other barrier destruction does, however, significantly improve the fit of Model 4 over Model 3, indicating the importance of considering both perspectives[5].

Given the limited nature of the dummy variables, I next use some richer measures: SKILL LOSS to represent competence destruction, and MES to represent other barriers. The results of this analysis are presented in Table 7.4. In Model 1, I test for the gross effect of SKILL LOSS, without controlling for MES. Consistent with what the competence-based literature would predict, the estimated coefficient of SKILL LOSS is positive and moderately significant. In

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[4] In tests of the equality of the coefficients, I am unable to reject the null hypothesis that the coefficient of the *COMPETENCE-DESTROYING * OTHER BARRIER DESTROYING* dummy equals the coefficient of the *COMPETENCE-DESTROYING * OTHER BARRIER ENHANCING* dummy. Likewise, I am unable to reject the null hypothesis that the coefficient of the *COMPETENCE-DESTROYING * OTHER BARRIER DESTROYING* dummy equals the coefficient of the *COMPETENCE-ENHANCING*OTHER BARRIER DESTROYING* dummy.

[5] A likelihood ratio test is significant at the $p<.01$ level. Chi squared statistic = $-2(-100.6-(-94.2)) = 12.8$, with a change of one degree of freedom

Model 2, I test for the gross effect of other factors by examining the effect of MES on entry. Consistent with prior empirical work on barriers to entry, the estimated coefficient is significant and negative. When both SKILL LOSS and MES are included in Model 3, however, MES is still significant whereas SKILL LOSS is not. By considering just competence and ignoring other factors, the results were misleading. Once more, this result demonstrates the dangers inherent in considering only a single perspective without controlling for the other.

7.3 Modeling Market Share

7.3.1 Overview

I next examine the determinants of product market share in order to understand the post-entry performance of new entrants vs. incumbents. The sample only includes only products from competence destroying generations: the analog phototypesetter, CRT phototypesetter and laser imagesetter generations. Hot metal products are excluded since all firms in that generation were new entrants and a comparison with incumbents from a prior generation is obviously not possible. The postscript laser imagesetter generation is excluded due to a lack of data availability. The three included generations, however, allow a comparison of both competence and other barrier destruction (analog phototypesetters) with just competence destruction (CRT phototypesetters and laser imagesetters).

7.3.2 Measures

The dependent variable

Market Share

In order to capture the initial effect of a product in the marketplace, unit market share is measured for the first three full years of a product's life. Each product which lasts three years therefore has three observations. Products withdrawn after one or two years have only one or two observations. Market share is calculated within a given generation of technology. This allows for a distinction between incumbent performance in different generations and also controls for the stage of diffusion of the technology.

Controls

Price

Price is the manufacturer's listed product price in current dollars for each of the three years in which its market share is measured. Since price and market share are jointly determined by product characteristics, I instrument for price with product speed, product width-capacity, and time period dummy variables. Product speed is the maximum number of newspaper lines per minute (nlpm) that a particular product can generate. This measure is standard in the industry. Width-capacity is the maximum width, expressed in picas, that a machine can produce. Some machines, for instance can only produce output 33 picas wide - about a 5 inch column of text - whereas others can produce text as wide as a newspaper page. Six time period dummies are included to account for price changes over time. A regression of price on these instruments and a constant results in an R-square of 0.53.

Competition

The effect of competition is captured by the number of products competing in a generation of technology in a given year. Clearly the more competitors there are, the lower one would expect market share to be.

Growth

Growth is measured in the same manner as in the entry models, as the average unit growth in a technological generation for the prior three years. It is expected that a product announced during a high growth period has a higher likelihood of gaining market share. It is generally easier to gain new sales as opposed to stealing existing customers, especially given the high switching costs in the industry.

Measures of experience

First product

This dummy variable is set equal to one if a product is the first a firm has shipped in a given generation of technology. Since a firm has little experience in the new technology, one might expect it's first product to be less successful than subsequent efforts. The expected sign of First Product is therefore negative.

Incumbent dummy

The incumbent dummy is set equal to one if the manufacturer of a product also shipped products in the prior generation. As discussed in Chapter 2, the competence-based literature predicts that when a technological shift is competence destroying, being an incumbent should have a negative effect on performance. Controlling for the effect of other barriers, however, I expect a negative coefficient only when both other barriers and competence are destroyed. If just competence is destroyed, and other barriers remain high, then, depending upon the strength of the two effects, it is possible for incumbents to be buffered from the effects of competence destruction. Since we don't know which effect is stronger, the expected effect of being an incumbent in this case is uncertain.

Prior experience

An incumbent's experience in the preceding generation is measured in two ways. First I count the number of years of experience in the preceding generation at the time the current product is shipped. This measure should capture the routines and procedures embedded in the product development organization of incumbent firms. The longer the firm has participated in the prior generation, the more difficult these routines should be to change. Second, I count the cumulative number of units shipped in the prior generation at the time the current product is shipped as an alternative measure of prior competence.

These two measures are simply richer ways of capturing the potential liability of incumbent experience, and the expected effects on performance are the same as for the incumbent dummy variable. While more experience in the prior generation should handicap a firm when both competence and other barriers to entry are destroyed, the effects when other barriers remain strong are uncertain. It is possible that other barriers buffer incumbents from the effects of competence destruction.

Summary

Variable definitions, measures and descriptive statistics are summarized in Tables 7.5 and 7.6.

Table 7.5
Product Market Share Model - Variables and Measures

Variable	Measure
MARKET SHARE	The unit market share of a product in a given year and generation of technology
Measures of Experience	
INCUMBENT DUMMY	Dummy variable set equal to one if a firm was present in the prior generation
STOCK OF PRIOR EXPERIENCE	Two measures are used: 1) The number of years of experience a firm has in the prior generation. 2) The cumulative number of units a firm shipped in the prior generation
FIRST PRODUCT	Dummy variable set equal to one if this is the first product in the current generation developed by this manufacturer
Controls	
GROWTH	Average unit growth for the prior 3 years for the given generation
NUMBER OF PRODUCTS	The total number products competing in the generation at the beginning of the period
PRICE	Predicted price using product speed, width and time period dummies as instrumental variables

Table 7.6
Market Share Model Descriptive Statistics

	Mean	**Standard Deviation**	**Minimum**	**Maximum**
MARKET SHARE	15.2	15.0	.10	73.8
FIRM EXPERIENCE IN PRIOR GENERATION (YEARS)	18.2	28.0	0	85
FIRM EXPERIENCE IN PRIOR GENERATION (UNITS)	12737	17435	0	73000
FIRST PRODUCT	.47	.50	0	1
GROWTH	.53	.46	-.07	1.97
NUMBER OF COMPETING PRODUCTS	11.1	4.4	2	18
PRICE	60065	77247	4500	385000
SPEED (NLPM)	354	557	6	3000
WIDTH	57	19	27	108

7.3.3 Results of modeling market share

Controls

The results of two-stage least squares estimation of market share are displayed in Table 7.7. The signs of the three control variables are all in the expected direction and all highly significant. Higher price clearly has a negative effect on unit share. More competition also has a negative effect. More competitors make it more difficult to establish a new product. Finally, growth has a positive effect. When the market is growing it, a new product can gain share from new buyers without having to steal share from established players.

The effect of experience

As expected, first products in a generation perform significantly worse than subsequent products - the coefficient of FIRST PRODUCT is negative and significant across all specifications. It appears that as a firm gains experience in the current generation, its performance improves. One might expect that the negative effect of a first product would be even stronger for incumbents than for new entrants since all technological generations included in the sample are competence destroying. The interaction of the FIRST PRODUCT and INCUMBENT dummies, however, was consistently insignificant when tested in alternative specifications.

I next examine Models 1 through 6 in order to discover whether other barriers to entry are in fact buffering incumbents from the effect of competence destruction. Model 1 tests for the effect of competence-destruction on incumbent market share through the inclusion of an incumbent dummy. This is the test that might be performed in a traditional analysis of competence destruction and does not control for other effects. The coefficient of the INCUMBENT dummy is negative and significant, consistent with what this literature would predict. If one went no further, one might assume incumbents were generally disadvantaged by competence destruction.

Table 7.7

Determinants of market share using two-stage least squares

Dependent Variable = ln (Market share)

Sample includes only competence-destroying technological generations, n= 154

	Model					
	1	2	3	4	5	6
CONSTANT	6.12***	6.07***	5.8***	5.56***	5.6***	5.5***
	(.54)	(.53)	(.46)	(.55)	(.51)	(.54)
PRICE	-.97***	-1.04***	-.86***	-.83***	-.80***	-.80***
	(.25)	(.24)	(.22)	(.24)	(.24)	(.26)
NO. COMPETING PRODUCTS	-.28***	-.27***	-.25***	-.25***	-.25***	-.24***
	(.03)	(.03)	(.03)	(.03)	(.03)	(.04)
GROWTH	.008**	.007**	.006**	.006**	.005*	.005
	(.003)	(.003)	(.003)	(.003)	(.003)	(.003)
FIRST PRODUCT	-.66**	-.72***	-.72**	-.70***	-.52**	-.51*
	(.21)	(.20)	(.20)	(.21)	(.21)	(.22)
INCUMBENT	-.64***					
	(.19)					
*INCUMBENT * OTHER BARRIER DESTROYING*		-1.18***				
		(.22)				
*INCUMBENT * OTHER BARRIER ENHANCING*		-.22				
		(.23)				
PRIOR EXPERIENCE (YEARS)			-.014***			
			(.003)			
*PRIOR EXPERIENCE (YEARS) * OTHER BARRIER DESTROYING*				-.015***		
				(.003)		
*PRIOR EXPERIENCE (YEARS) * OTHER BARRIER ENHANCING*				.002		
				(.015)		
PRIOR EXPERIENCE (UNITS)					-.007	
					(.005)	
*PRIOR EXPERIENCE (UNITS) * OTHER BARRIER DESTROYING*						-.010*
						(.005)
*PRIOR EXPERIENCE (UNITS) * OTHER BARRIER ENHANCING*						.004
						(.010)
OTHER BARRIER DESTROYING DUMMY				.16		-.05
				(.32)		(.32)
Adjusted R^2	.32	.40	.38	.39	.29	.30

Standard errors in parentheses, *** p < .01, ** p < .05, * p < .10

In Model 2, however, controlling for other barrier destruction significantly affects the results. When other barriers are destroyed in addition to competence, the effect of being an incumbent is still significant and negative. When other barriers are enhanced and competence destroyed, however, the effect of being an incumbent no longer hurts performance significantly. Despite the technological disadvantage imposed by competence destruction, it appears that other barriers are sheltering firms in the industry - being an incumbent has not handicapped them. This result is consistent with the descriptive data in Chapter Six which showed new entrants achieving a market share of 89% in the analog phototypesetter generation as opposed to shares of 16% and 12% respectively in the CRT and laser generations.

I next substitute for the incumbent dummy variable with more sophisticated measures of the incumbent's prior experience - years of experience and units produced. Once more, I begin by examining the effect of competence without controlling for other factors. In Model 3, I find that an incumbent's prior experience in terms of years has a negative and significant effect on market share. On the surface, this result provides evidence of incumbents being at a disadvantage. When I control for other barriers in Model 4, however, I find that the significant negative effect only holds if both competence and other barriers are destroyed. When other barriers are enhanced, the estimated coefficient is now positive, and no longer significant. Once more, other barriers appear to be buffering incumbents from the effects of competence destruction.

Finally in Models 5 and 6, I repeat the analysis using units produced in the prior generation to measure prior experience. The number of prior units alone appears to have an insignificant effect on performance (Model 5). When I control for other barriers in Model 6, however the same pattern as above emerges. When other barriers are destroyed in addition to competence, then the number of prior units has a moderate negative effect on market share. When other barriers remain strong, however, the number of prior units is no longer a liability.

7.4 Summary

This chapter has quantitatively tested the hypotheses developed in Chapter Two as well as the intuition developed in Chapter Six. It has demonstrated that while incumbents do suffer in terms of technological performance when faced with a competence destroying shift, they do not necessarily suffer in the marketplace. If other barriers to entry remain strong, then incumbent firms can be buffered from competition long enough to develop new capability and compete effectively with new entrants. The next chapter explores the specific ways in which incumbent develop these new capabilities.

Chapter Eight

Integrating External Technological Knowledge: Case Studies

8.1 Introduction

As shown in Chapter Seven, other barriers to entry can provide incumbents a buffer from the competition of technically superior new entrants. If incumbents do not eventually develop new technological capability, however, they will fail to survive in the marketplace. In addition, incumbents do not always have the luxury of a competitive buffer. Often competence-destroying technological shifts are accompanied by the destruction of other barriers to entry, and the incumbents must adapt quickly to the new technology or die. It is therefore important to understand how incumbent firms can best develop what Teece, Pisano and Schuen call "dynamic capabilities...the capacity of a firm to renew, augment, and adapt its core competencies." (1992, p.18).

This chapter argues that a key contributor to dynamic capabilities in a technological context is a firm's ability to identify and integrate unrelated external technological knowledge, in other words, its ability to develop "absorptive capacity" (Cohen and Levinthal, 1990). Since, as seen in Chapter Four, competence-destroying technological change generally originates outside an industry, established firms are faced with the task of acquiring new technological expertise from outside sources. Established firms differ substantially in their ability to acquire and integrate unrelated external knowledge, and the source of these differences is explored through case studies of Mergenthaler Linotype, Intertype, Monotype, and Compugraphic. The first three firms were strong competitors in the original hot metal era, but only Mergenthaler was successful in making the transition to subsequent generations of technology. Compugraphic was the most successful of the entrants in the second generation of technology, analog phototypesetting.

I find that the superior incumbent performance is dependent upon building absorptive capacity in the new technology. I distinguish between two elements of absorptive capacity: 1) prior related knowledge and 2) an external communication infrastructure. While Cohen and Levinthal focus on prior related knowledge in the form of internal R&D as a determinant of absorptive capacity, I find that without an infrastructure to tap external knowledge, firms have difficulty accessing it. Prior related knowledge is a necessary, but not sufficient element of absorptive capacity.

If absorptive capacity is so important, then why don't all firms simply invest in developing it? The answer is twofold. First, not all firms recognize the need to make internal investments in a new technology; recognizing the relevance of a particular technology amidst many possible technologies is not trivial. Second, even if a firm makes internal investments, it needs to develop an external communication infrastructure. Internally focused firms may not recognize the need to develop this infrastructure, and even if they do, it is not a simple task, but a cumulative process. Know-how in effectively managing external relationships builds over time, and without experience, firms are less likely to succeed in integrating external knowledge.

Given the importance of recognition and of experience in managing external relationships, I find that absorptive capacity in a previous generation of technology helps to establish absorptive capacity in a new generation. The source of this positive effect is the firm's external communication infrastructure. Ongoing scanning and screening increases the likelihood of recognition and thus development of the first element of absorptive capacity, internal investment in a new technology. The firm's culture and experience in forming external linkages also eases the development of the second element, a new external communication infrastructure. Even if the firm is interacting with different actors, it's prior relationships can serve as a template for the formation of new ones. Combined, the initial investment and new infrastructure form the beginning of absorptive capacity in a new technological domain.

I summarize by discussing possibilities for future research. In particular, I identify other factors that may contribute to dynamic capabilities, including the use of geographically distributed R&D locations.

8.2 Sources of technological knowledge

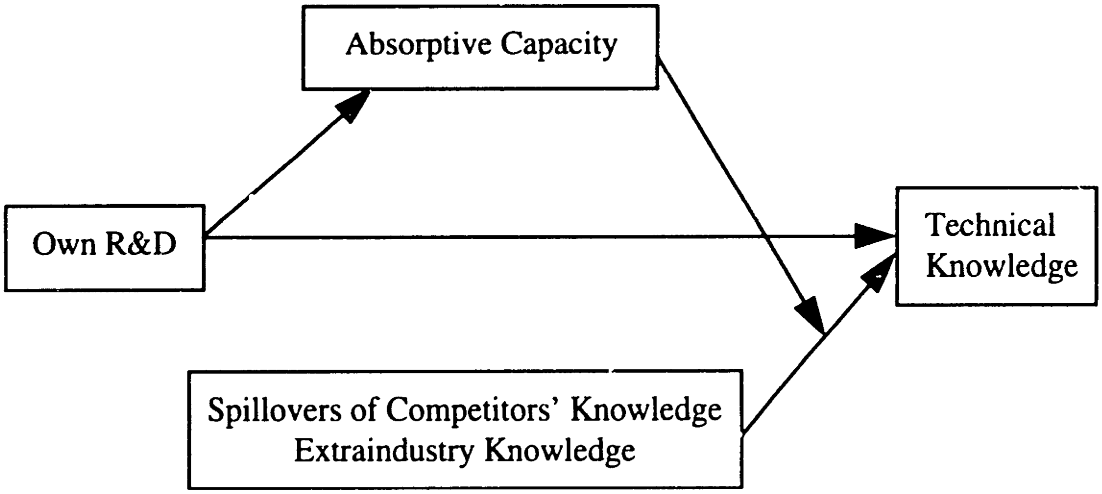
In general a firm has two basic sources of technological knowledge, its own internal research and external knowledge. Internal knowledge cumulates as employees of the firm do research in a particular area. The company may also hire new employees with a specific technical expertise. Alternatively, the firm can attempt to tap the technological knowledge of other organizations. How a firm should best tap external knowledge, however, is unclear, especially when that knowledge is unrelated to the firm's area of expertise. Since firms facing competence-destroying technological change must often look outside for technological expertise, it is important to understand this process. In this section I review two relevant streams of literature.

8.2.1 Cohen and Levinthal's model of absorptive capacity

Cohen and Levinthal (1990, p.128) coined the term "absorptive capacity" to describe a firm's "ability to recognize the value of new information, assimilate it, and apply it," and argue that "prior related knowledge confers... absorptive capacity." In other words, firms that have invested in internal R&D related to a particular technological domain will be more successful at absorbing related external information. The reason for this effect is that individuals already working in a given area are better able to judge and internalize familiar information as well as communicate with external experts. The following is a reproduction of Cohen and Levinthal's (1990, p. 141) model:

Figure 8.1

Model of Sources of a Firm's Technical Knowledge



Two salient implications emerge from this model. First, a firm's investments in R&D have a second order effect in that they also add to the firm's absorptive capacity and enable the firm to better access external knowledge. For a firm investing in a competence-destroying technology, this implies that initial investments early on are especially important in that they open a window for the acquisition of relevant external knowledge. Since absorptive capacity is cumulative, if a firm enters the new technology too late, it may be "locked out."

Second, developing absorptive capacity in a new technological domain may be especially difficult in that some technologies "may be too distant from the firm's existing knowledge base -- its absorptive capacity -- to be either appreciated or accessed." (p.137) In other words, "the firm needs to have some absorptive capacity already to value it appropriately" (p.138) This result is troubling for incumbents facing competence-destroying change in that despite benefiting greatly from initial investments, the firm may not recognize the need to invest.

8.2.2 The role of an external communication infrastructure

While investment in a technological area increases a firms ability to absorb related external knowledge, that knowledge must somehow be transmitted from the outside source to the firm. Cohen and Levinthal (1990) assume that transmission of the external knowledge is not a problem -- in other words, that an effective communication infrastructure is in place -- and focus instead on the need for prior related knowledge. However in later work (Cohen and Levinthal, 1994, p.228) they acknowledge that "While prior related knowledge may be the key component of absorptive capacity, there may be others. For example, the establishment of close relationships with extramural knowledge sources (e.g. suppliers, buyers or universities) that create and strengthen information channels may also contribute to a firm's absorptive capacity." Nicholls-Nixon (1993) also argues that external technology sourcing practices form an important element of absorptive capacity.

The innovation literature suggests that external relationships and communication linkages cannot be assumed to exist and are, in fact, a critical part of a firm's ability to absorb external knowledge. I use the phrase "external communication infrastructure" to describe these relationships and include elements such as technological gatekeepers, informal know-how trading relationships, technology scanning mechanisms, and ongoing relationships with suppliers, customers, outside consultants and universities. I briefly discuss these elements.

Allen (1976) found that the majority of engineers and scientists do not keep up to date on developments in the technical literature. They do not read the relevant literature, even when it might help them to solve a technical problem. Instead this knowledge generally enters the firm through "technological gatekeepers." These individuals identify and filter external technological information and then communicate it to others in the organization.

Rewarding and encouraging gatekeepers can therefore facilitate the absorption of external knowledge.

Another way that external knowledge is transmitted to the firm is through "informal know-how trading." Schrader (1990) and von Hippel (1987) found that when technical personnel attend industry conferences, they often exchange technical information with individuals from competing firms in tit-for-tat relationships. This know-how trading was an important source of technical information for each firm. In order to form a productive tit-for-tat relationship, however, the parties involved must have ongoing interaction. Consistent attendance at industry conferences is therefore important.

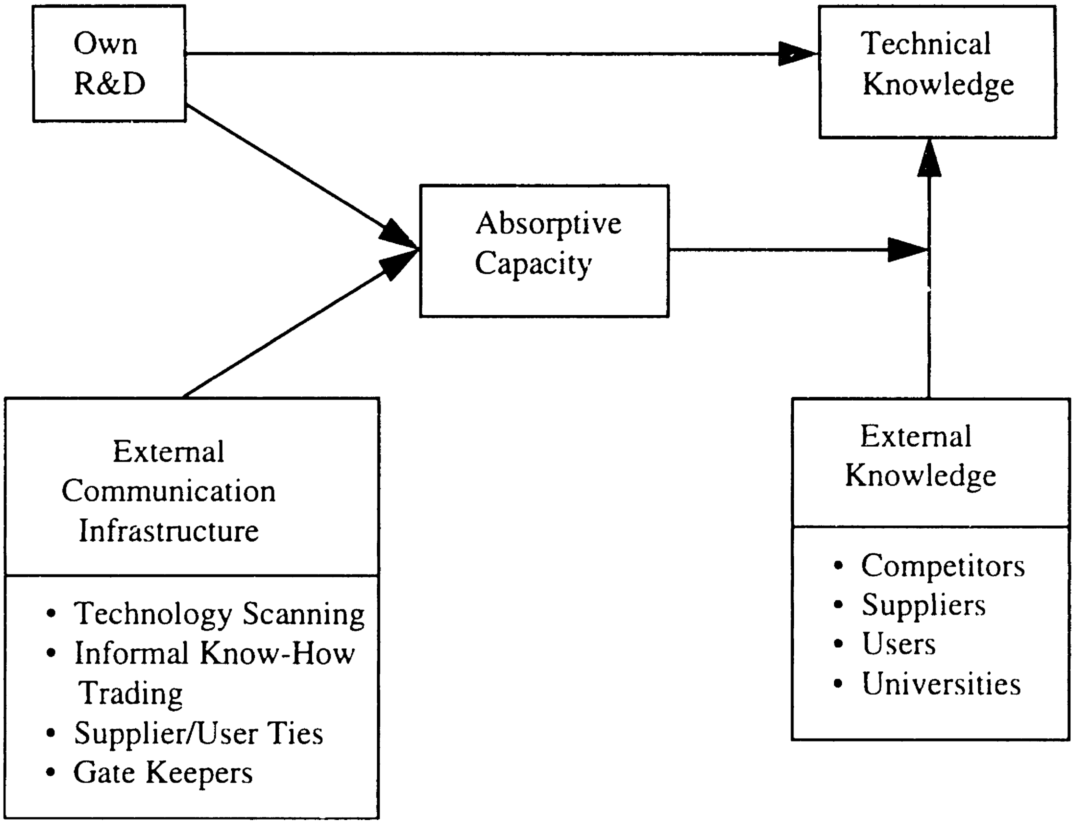
Events such as industry conferences and trade shows are just one part of a company's overall technology scanning apparatus. Other mechanisms for technology scanning include formal screening of patents and technical journals. Formal screening can supplement the job of a technological gatekeeper, or partially substitute in the situations where there is no gatekeeper. Technology scanning was found to be the second most important part of a technology acquisition strategy (internal R&D was the most important) in a study of Japanese, US and Swedish firms (Granstrand, 1992).

Finally, ongoing relationships with suppliers, customers, outside consultants and universities can facilitate the transmission of external knowledge. von Hippel (1988) finds that suppliers and customers often innovate, and can be a prolific source of ideas. Developing ongoing relationships, however is key once more. As Allen (1976) found, ongoing relationships with outside consultants helped the performance of development teams, whereas infrequent contact did not. He hypothesizes that the reason for this disparity has to do with the ability of the individuals involved to communicate effectively. Through ongoing contact, individuals learn to "speak the same language," and better communication facilitates learning.

Given the importance of an external communication infrastructure in facilitating the transmission of external knowledge, I suggest a modification to Cohen and Levinthal's original model and explicitly include the infrastructure as a contributor to absorptive capacity (see Figure 8.2). As seen in the following section, an external communication infrastructure is an important contributor to absorptive capacity.

Figure 8.2

Sources of a Firm's Technical Knowledge: A Revised Model



8.3 Evidence from the typesetter industry

Incumbent firms in the typesetter industry have had varying degrees of success in surviving competence-destroying technological change. In order to understand differences in performance, I compare the evolution of four firms in the typesetter industry: the three original players Mergenthaler Linotype, Monotype and Intertype, and the most successful new entrant, Compugraphic.

The first three firms provide an interesting comparison in that, despite their seemingly similar backgrounds, they varied significantly in their ability to respond to competence-destroying technological change. All three of these firms had their origins in the beginning of the typesetter industry and spent over 50 years making incremental changes to their hot metal machines. They each faced the competence-destroying shift to analog phototypesetting and, as discussed in Chapter Six, responded initially with machines that imitated their hot metal machines. Mergenthaler Linotype, however, recovered, and Linotype-Hell, the descendant of the original company is a leading typesetter manufacturer today. Monotype is "alive" today, but is a shadow of its former self, and Intertype exited the typesetter industry in 1984 after a slow and lingering demise.

As the most successful entrant in the second generation of technology, Compugraphic had a very different background from Mergenthaler when it faced the competence-destroying shifts to CRT and laser technology. The two firms provide an interesting contrast in that despite their differences, both were very successful in making the transitions. Today Agfa Compugraphic (the descendent of Compugraphic) is Linotype-Hell's major competitor. A comparison of the history of all four of these firms provides a rich sense of how dynamic capability, in the form of absorptive capacity, evolves.

8.3.1 The importance of absorptive capacity

At a very basic level, by examining the transitions of the case study firms, it is clear that the development of absorptive capacity is crucial to developing expertise in a competence-destroying technology. Table 8.1 lists each of the case study firms, whether they developed absorptive capacity in the new generation, and how successful they were at competing in that generation. Consistent with the preceding discussion, when measuring whether a firm has developed absorptive capacity in a new technology, I measure both its level of prior related knowledge (own R&D) and its external communication infrastructure. If both elements are present, then I categorize the firm as having developed absorptive capacity in that technology. The details that support these categorizations are presented in the following sections.

Table 8.1

The Effect of Absorptive Capacity on Incumbent Performance in Competence-Destroying Technological Transitions

Firm	Transition	Absorptive Capacity Developed?	Successful Transition?	Market Share in the new technology
Mergenthaler	Hot metal to Analog Phototypesetter	Yes	Success	8%
Mergenthaler	Analog Phototypesetter to CRT	No (US)	Success	35%
Mergenthaler	CRT to Laser	Yes	Success	30%
Monotype	Hot metal to Analog Phototypesetter	No	Failure	1%
Monotype	Analog Phototypesetter to CRT	No	Failure	0%
Monotype	Laser	Yes	Success	10%
Intertype	Hot metal to Analog Phototypesetter	No	Failure	2%
Intertype	Analog Phototypesetter to CRT	Yes	Failure	2%
Compugraphic	Analog Phototypesetter to CRT	Yes	Success	32%
Compugraphic	CRT to Laser	Yes	Success	25%

Table 8.2 summarizes this information. I find that successful transitions were overwhelmingly accompanied by the development of absorptive capacity (five of six) and unsuccessful transitions by a lack of absorptive capacity (three of four).

Table 8.2

The Effect of Absorptive Capacity on Incumbent Transition Success Summary

		Successful Transition	**Failed Transition**
Absorptive Capacity Developed ?	**Yes**	5	1
	No	1	3

Obviously, this is a small sample, and one hesitates to draw conclusions based simply on these numbers. They are, however indicative of a clear pattern. Through in-depth examination of the observations in the sample, one gets a better understanding as to how absorptive capacity (or the lack thereof) affected incumbent transitions.

8.3.2 How absorptive capacity evolves: Firm histories[1]

In this section I describe how each of the case study firms developed (or failed to develop) absorptive capacity in a new generation of technology, and how absorptive capacity affected the firm's performance.

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[1] The information contained in these histories comes from a combination of interviews, firm archives, and other industry sources. See Appendix A and the technical bibliography for a list of sources.

Mergenthaler Linotype

Mergenthaler Linotype was founded in 1886 and was the dominant typesetter firm throughout the hot metal era, capturing over 50% hot metal sales between 1901 and 1970, when US production ceased. In making the transitions to second, third and fourth generation machines, Mergenthaler was extremely successful at identifying and integrating new, unrelated external technological knowledge. The US organization developed absorptive capacity in two of the three new generations of technology, and in the generation it missed, the German organization developed absorptive capacity. Table 7.1 chronicles key products developed by Mergenthaler in each generation of technology and serves as a reference point for this discussion of the evolution of absorptive capacity.

Mergenthaler's development of absorptive capacity in hot metal

Mergenthaler had a high level of absorptive capacity in hot metal technology. It continually invested in incremental innovations to the hot metal machine, and it developed a communication infrastructure to support acquisition of information from Intertype, its main competitor. Since the two firm's machines were so similar, service personnel developed informal know-how trading relationships and often exchanged information when attempting a difficult repair. When useful, the knowledge gleaned from these exchanges made its way to the development group. In addition, the US development groups of both organizations were located in New York, facilitating direct informal interaction among developers. So while the firm did not formally acquire external technology, it closely tracked developments by Intertype.

Table 8.3

Mergenthaler Linotype: Integration of External Technological Knowledge

Year	Product	Absorptive Capacity		External Knowledge Formally Accessed	Total Units Sold*
		Prior related knowledge? (Own R&D)	External communication infrastructure?		
Hot Metal Typesetting: absorptive capacity developed					
		Yes	Yes		
1911 1950	Hot metal linecasters	* high	* Informal know-how trading with Intertype	* none	111,000
Analog phototypesetting: absorptive capacity developed					
		Yes	Yes		
1950	"Hot-metal imitation" phototypesetter	* none	* none	* none	0
1959	Linofilm	* minimal	* starting university consultations	* Columbia University professor for lens design and optical engineering	330
1964	Linofilm Quick	* high	* ongoing university consultation * know-how trading * patent screening	* Columbia University professor for lens design and optical engineering	400
1970	Linofilm VIP	* high	* ongoing university consultation * know-how trading * patent screening	* Columbia University professor for lens design and optical engineering * Microdata as supplier of computer processor	3720
Digital CRT phototypesetting: absorptive capacity not developed in US, developed in Germany					
		No	No		
1967	Linotron 1010	* some CRT research in 1940's	* none	* joint development with CBS Labs	5
1968	Linotron 505	* from CBS	* none	* acquired K.S. Paul	480
1978	Linotron 202	* low in US * high in UK	* ongoing (UK)	* none	6600
1979	CRTronic	* high in Ger.	* work with UK	* tech transfer from K.S. Paul	7440
Laser imagesetting: absorptive capacity developed					
		Yes	Yes		
1980	Omnitech 2000	* none	* none	* Hired laser scanner expert/ group in Connecticut	1280
1985	Linotonic 101/100/300	* high	* supplier/industry relationships	* none	11750

* estimate of cumulative sales through 1990

Mergenthaler also developed strong international development groups during the hot metal era. The original Linotype technology was licensed to a British firm in 1889 and to a German firm in 1896. In 1909 the US company purchased large interests in both. The foreign subsidiaries did their own manufacturing and also developed their own incremental improvements to the Linotype machine. Some sharing of product innovations between the US and UK groups took place, once more encouraging an external perspective. The German organization, however, worked independently, although in later generations it also cooperated with the other groups.

Mergenthaler's development of absorptive capacity in analog phototypesetting

When the second generation of technology, analog phototypesetting began, Mergenthaler invested early despite a lack of prior related phototypesetter knowledge. Since individual inventors had been doing research in phototypesetting throughout the hot metal era, engineers at Mergenthaler were aware of the technology from various trade shows and publications.

The firm's initial effort to develop a phototypesetter was not successful. As discussed in Chapter Six, the first machine was developed by hot metal engineers, and the result was an "imitation hot metal" machine. Despite being displayed at a trade show in 1950, the machine was never brought to market, based on extremely negative input from the sales organization. As an internal memo from the VP of Sales to the sales force dated October, 1952 states,

> " Lately we have been receiving a number of requests for information regarding our Linofilm machine...We developed this machine and showed it at Chicago to demonstrate that we had available a machine that would do anything that was presently available on the market. To be very specific, this machine can do what the Intertype Fotosetter can do. However, we ...do not consider this machine the answer to the photo-composition problem...Anyone who purchases a photo-

> composing machine should reasonably look for some savings or greater facilities than are now offered, and neither the Linofilm nor the Fotosetter offers these advantages... Just tell your customers that we are not yet ready to put on the market a machine for photocomposition. Do not write in and ask us when we think our photo-composing machine will be ready - we actually don't know."

The first analog phototypesetter to be commercialized by Mergenthaler, also called the Linofilm, didn't arrive until 1959. The knowledge from the earlier effort appeared to have had some influence in that the need for external expertise was clearly recognized. The new Linofilm development team comprised almost all newly hired engineers, and an external consultant, a professor from Columbia, designed the critical optical subsystem. A new director of the Research and Engineering Division, Louis Rosetto, had been appointed in 1953, and he had strong ties to Columbia University. As a result, other links with Columbia professors were also encouraged.

The arrival of a new CEO, Jack Keller, in 1956 served to further emphasize the focus on acquiring external technology. Keller immediately cut back on hot metal R&D and clearly focused the firm on phototypesetter development. Engineers were encouraged to attend trade shows and avidly examine competitor's products as well as meet with suppliers of potential new technologies. As one Mergenthaler development engineer from this era stated in an interview,

> "We didn't invent any technology. We observed existing technology and said, 'How could we use that?'. "

The Linofilm was not particularly successful. Part of the problem may have been that the phototypesetter developers were still immersed in the hot metal culture, with members of the project team part of the same engineering function as the hot metal developers. In fact, hot metal development was going on concurrently in the same building. The firm was, however gaining expertise from outside sources, and at the same time building its infrastructure in order to continue accessing external knowledge.

With both prior related knowledge and external linkages in place, follow-on development efforts were much more successful at exploiting external technology. The Linofilm VIP in 1970 was the most successful of the subsequent developments. This machine was the first to incorporate a computer, and, consistent with a strategy for integrating external knowledge, that part of the machine was developed in conjunction with Microdata, an outside supplier.

While the US organization was developing analog phototypesetter technology, the UK and German organizations were continuing to make incremental improvements to the hot metal machine. Phototypesetter products were imported from the US. In about 1965, however, the German organization felt that there was an opportunity to develop a phototypesetter targeted at the European market. Berthold, an old line German type foundry from the late 1800s had entered the typesetter market in 1967 and was experiencing a great deal of success. A new German R&D group, distinct from the hot metal group, was therefore formed in order to develop a competing product. The two products developed, the Linofilm Europa in 1970 and the Linotronic in 1976, had moderate success, but only in the German market. More importantly, they formed a foundation for further German development efforts and began to integrate the German organization into the broader German printing community.

Mergenthaler's failure to develop absorptive capacity in CRT technology

The culture of looking for external sources of technology in analog phototypesetting was clearly established, and so a collaboration with CBS Labs in 1965 to develop its first CRT machine was easily acceptable by the US Mergenthaler development organization. In addition, in the late 1940's

Mergenthaler had done some preliminary research into using CRT's in typesetting, but had determined that the resolution wasn't fine enough for typography (Corrado, 1965). Although it was far removed, this prior related knowledge may have helped the firm decide to invest in the new technology.

The product developed by Mergenthaler and CBS, the Linotron 1010, had been requisitioned by the US Government Printing Office, and in the end, the product was technically complex and overpriced, so very few units were sold. Ideally, however, Mergenthaler should have absorbed some knowledge of CRT technology from its relationship with CBS. Unfortunately, the amount of knowledge transferred was minimal. Mergenthaler had invested in developing the software component of the machine and had not directly invested in developing any CRT technology, leaving that portion of the project to CBS. As the Mergenthaler project head stated in an interview,

> " There was very little CRT technology transferred. We focused on getting our part done and didn't really understand what CBS was doing."

The lack of absorptive capacity (particularly own R&D) had clearly hurt Mergenthaler's ability to benefit from the collaboration.

At the end of this project, Jack Keller, CEO, felt that the firm still needed to go outside to acquire CRT expertise. Despite the "failure" of the CBS alliance, Mergenthaler had absorbed enough knowledge to evaluate acquisition candidates with CRT technology, and in 1968, a British firm, K.S. Paul was acquired (and renamed Linotype-Paul.) As will be discussed later, Monotype had declined the opportunity to acquire K.S. Paul before Mergenthaler bought it.

K.S. Paul had developed a CRT machine which Mergenthaler sold as the Linotron 505. This product was moderately successful, and its successor, the Linotron 202 was hugely successful. K.S. Paul had a strong external communication infrastructure, especially with suppliers and users, and continued to leverage those relationships. For instance Ronald McIntosh, one of the developers of the Linotron 505 machine had an ongoing relationship with Arthur Phillips, the director of the Her Majesty's Stationery Office[2] (the equivalent of the US Government Printing Office).

While K.S. Paul had continued to invest in absorptive capacity, the US organization never developed expertise in CRT technology. Some linkages between the US and UK groups were developed for the Linotron 202, and the US organization contributed to the software used in the machine, but the US organization never acquired enough expertise to develop a CRT machine of its own. As a whole, however, Mergenthaler was successful in making the transition in that it learned enough about the technology to recognize its own inability and acquired a firm with the necessary skills.

While K.S. Paul did not transfer technological knowledge to the US R&D organization, it was successful in transferring knowledge to Mergenthaler's German R&D organization. An explicit effort to transfer knowledge was made in the mid-1970's, with German electrical engineers visiting the UK on multiple occasions. Since the new German development group had only existed for about 10 years, it was not mired in analog phototypesetter technology and was successful at integrating new individuals with CRT expertise as well as working with the UK. The German group therefore did develop absorptive capacity in the CRT generation. The CRTronic, their first CRT machine, was a desktop model that had huge success, not only in Germany, but worldwide.

Mergenthaler's development of absorptive capacity in laser imagesetting

Mergenthaler benefited from its prior communication infrastructure in the transition to laser imagesetters. When the first laser imagesetter was announced

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[2] When I interviewed Ronald McIntosh at his home in 1994, he was still in contact with Arthur Phillips despite the fact that they had both retired. In addition, in the acknowledgments to his 1980 book, *Handbook of Computer-Aided Composition*, Phillips states, "I have to thank Ronald McIntosh for many helpful discussions over some fourteen years on the operation of CRT phototypesetters."

in 1976, Mergenthaler had yet to invest in the technology. Once more the firm looked outside for expertise. Through contacts with suppliers, Linotype-Paul became aware of an individual developing laser scanners for fax transmission. He was brought to the US, and development of a laser imagesetter began. The development group, which comprised both new-hires and some existing employees, was located in Connecticut, away from the main Mergenthaler facility. By assigning internal employees to work with the outside "expert" a base of knowledge was built in the US organization. The result of this effort, the, the Omnitech 2000, was not particularly successful, but the group had both developed internal capability as well as some external relationships. Further US development was moved to the main facility.

At the same time, laser development efforts also began in the UK[3] and in Germany. There was some effort to coordinate these efforts and transfer technology from the US, given the prior experience of the US organization. There was also clear competition between the groups. This competition was intensified by a change in ownership. Allied Chemical Corporation acquired the Mergenthaler Linotype Company in 1980,[4] and after an initial period of "hands-off" management the firm decided to consolidate the R&D groups to eliminate duplication. In 1983, the US organization announced the Linotronic 101, but before volume shipments of this machine began, the US and UK development and manufacturing organizations were closed down.

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[3] Linotype-Paul took over development responsibility from the original British subsidiary of Mergenthaler Linotype, Linotype & Machinery. The Linotype & Machinery hot metal development group slowly disappeared via natural attrition.

[4] The Mergenthaler Linotype Company was a distinct corporation from 1890 through 1963. At that point, in an unrelated diversification, it acquired Electric Autolite and Mergenthaler's official corporate name was changed to Eltra Corporation, with the Mergenthaler Linotype Company an unincorporated division. Eltra Corporation was acquired by Allied Chemical Corporation (later renamed Allied Corporation) in 1979. In 1987, Allied sold the Linotype division to the Commerzbank AG in Germany, and later that year a public offering for Linotype AG was made on the German stock exchange. In 1990, Linotype AG acquired Hell Graphic Systems and the name of the firm became Linotype-Hell AG.

The motives for choosing to keep the German group over the other two are unclear. One hypothesis, however, is that the strength of the German printing press sector accounted for the choice of Germany (Porter, 1990). With about 35% of world printing press production and 50.2% of world export production in 1985, Germany was clearly a leading force in the industry. By locating the development group near firms with printing press expertise, one could argue that developers had access to a stronger local network of external experts. The Germans had already established ties to the printing sector in the CRT generation, and could continue to leverage those ties in the laser generation.

The German group absorbed knowledge from the US organization as well as investing in its own laser experts. This, combined with a strong local network resulted in success in the laser generation. The follow-on to the US-developed Linotronic 101 was the Linotronic 100, and this machine as well as subsequent developments did very well in the world marketplace.

Intertype

Intertype entered the typesetter industry in 1911 when it began shipping a hot metal linecaster that copied most of its elements from Mergenthaler's Linotype machine. Like Mergenthaler, it had a high level of absorptive capacity in hot metal technology due to its continued investment and communication with Mergenthaler. Given their similarities, it is intriguing to try and understand why Intertype failed to make the transitions to subsequent generations of technology while Mergenthaler succeeded. In the following section, I contrast Intertype and Mergenthaler's evolution and argue that the failure to develop absorptive capacity is at least partially responsible for Intertype's performance. Table 8.4 serves a reference for the following discussion.

Table 8.4

Intertype: Integration of External Technological Knowledge

Year	Product	Absorptive Capacity		External Knowledge Accessed Formally	Total Units Sold*
		Prior related knowledge (own R&D)	External communication infrastructure		
Hot Metal Typesetting: absorptive capacity developed					
		Yes	Yes		
1911 - 1950	Hot metal linecasters	* high	* informal know-how trading with Mergenthaler	* none	35,000
Analog phototypesetter: absorptive capacity not developed					
		Yes	No		
1949	Fotosetter	* none	* none	* optical system help from Kodak	700
1964	Fototronic 480	* high in optics * none in EE	* relationships with central Harris R&D	* Harris corporate R&D provided electronics expertise	480
1972	Fototronic 600	* moderate	* none	* development contracted out	150
Digital CRT phototypesetting: absorptive capacity developed					
		Yes	No		
1968	Fototronic CRT	* none	* relationships with central Harris R&D	* Harris corporate R&D provided electronics expertise	25
1975	Fototronic 7000	* high	* external industry ties	* none	470

* estimate of cumulative sales through 1990

Intertype's failure to develop absorptive capacity in analog phototypesetting

As discussed in Chapter Six, Intertype's initial foray into analog phototypesetting was driven by its hot metal developers, and the result, the Fotosetter was an "imitation hot metal" machine. Upon initial examination, it would appear that Intertype was on the right track in terms of integrating external technical knowledge. In designing the machine, they clearly lacked expertise in optical engineering, and therefore had Kodak assist in the development of the optical/lens component of the machine. This relationship appears to have worked well, and some knowledge of optics was successfully transferred to Intertype. Unfortunately, Intertype did not perceive a need for expertise in electronics since the machine it was developing was mechanical. Therefore no investment was made in developing either internal expertise or external relationships with electronics experts.

Investments in electronics were further delayed by the "success" of the Fotosetter. As the very first phototypesetter on the market, the Fotosetter had a monopoly and achieved reasonable level of sales with about 700 units shipped. While Mergenthaler began investment in an electro-mechanical phototypesetter in 1950 after its decision not to pursue its "imitation hot metal" machine, Intertype continued to make improvements to the Fotosetter. The Intertype 1956 Annual Report states, "Your Corporation continues its research and development work in the field of photocomposition with special emphasis on enlarging the range of type and adding to the Fotosetter's utility." (p.4) Thus while the firm may have gained some expertise in optical engineering and lens design from it relationship with Kodak, it failed to develop electronics expertise.

In 1957 Intertype was bought abruptly into the electronic age when it was acquired by Harris-Seybold. Harris, traditionally a printer manufacturer, had embarked upon an ambitious plan to transform itself into an electronics company. In the process, Harris had developed some technology that would be useful in phototypesetting: stoboscopic light selection of characters from a spinning disk.[5] Recognizing the need for a font library in order to enter the industry, the firm acquired Intertype.

Intertype engineers worked with Harris' central R&D lab in the development of Intertype's first electro-mechanical phototypesetter, the Fototronic 480. While the engineers of both firms worked together, there is evidence that little technology was transferred. Since Harris had already done a great deal of the development work before the merger, Intertype had little to add. In addition, since Intertype's development group had little expertise in electrical engineering, they had difficulty internalizing what Harris did. Unfortunately, by the time the Fototronic 480 began shipping in 1964, Photon, a new entrant was also shipping a machine that was both faster and supported a larger number of fonts online. The Fotosetter 480 therefore did not do very well in the marketplace.

When Intertype subsequently decided to develop a low-cost phototypesetter, one that would not require the leading edge electronics expertise of the central Harris lab, the firm contracted the development out. There was little confidence in the ability of the Intertype group to develop the machine on its own. Instead of having some internal employees interface with the external team, Intertype waited until the development was complete and then had its engineers examine the "final product." The Intertype engineers felt a strong need to redesign the product, and the machine's announcement was delayed by about a year. The original external designers had no role in the redesign, and no technology was transferred from the outside team to the internal developers. The product, the Fototronic 600 was a dismal failure.

The lack of confidence in Intertype's development group and the subsequent disappointing relationship between Intertype and the external

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[5] This technology was similar to that of Photon, the first new entrant, and a patent dispute between the two firms was appealed all the way to the US Supreme Court where the judgment of the district court, that the Harris patents were invalid, remained intact.

developers can be traced to a combination of factors. First, the lack of confidence in Intertype's internal development indicates that the firm did not successfully absorb technical knowledge from Harris' central lab. Since Intertype didn't appear to invest a great deal in separate electrical expertise, the lack of transfer is not surprising -- Intertype lacked absorptive capacity.

Second, the relationship between Intertype and Harris' central R&D lab, while logical in that it leveraged Harris' expertise, also allowed the Intertype development group to become lazy in terms of establishing its own external contacts. Since Intertype had in-house experts available at Harris, it failed to develop other relationships. So while individuals at Harris' central lab may have developed an external communication infrastructure, the engineers at Intertype did not. This may have further eroded confidence in the group.

The lack of cooperation with the external developers of the Fototronic 600 and the subsequent redesign are indicative of the infamous NIH (not invented here) syndrome. Since the Intertype development group was internally focused, and not accustomed to accessing external knowledge from anywhere other than Harris' central lab, it may have had difficulty accepting external knowledge from another source.

Intertype's development of absorptive capacity in CRT technology

With the CRT generation of technology, the lack of local expertise within the Intertype organization became apparent, and separate investments were made in establishing requisite skills there. The first development was still collaborative with Harris' central lab, but Intertype also had its own experts. With its broad portfolio of technology in multiple electronics businesses, Harris had better access to CRT technology and provided the initial external linkages. This time however, more technology seems to have been transferred to Intertype, and subsequent machines were developed primarily by Intertype with minimal input from corporate. Intertype engineers also began to assume greater responsibility for external communication.

Despite the development of absorptive capacity in the CRT generation, Intertype failed to do well in the market. The firm's position had already declined during the 1960's and 1970's when sales of analog phototypesetters were growing, and it may have had difficulty convincing buyers that it was back on course. By the early 1980's when industry sales of CRT typesetters were increasing, Intertype's position had eroded to the point that Harris corporate decreased investment in typesetter development and shifted priorities to other electronics businesses. The last internally developed machine was announced in 1980, and Intertype stopped shipping typesetters in 1984.

Monotype

Monotype, based in the UK, entered the typesetter industry in 1890 and like Mergenthaler, was very successful through the hot metal era. The firm was unsuccessful, however in making the transition to the next generation of technology. Despite a recovery in the laser generation with assistance from the British government, the firm continues to falter today. Table 8.5 serves as a reference for the following discussion.

Monotype's lack of absorptive capacity in hot metal

Unlike Mergenthaler and Intertype, Monotype did not develop absorptive capacity in the hot metal generation. While Monotype made ongoing investments in incremental innovation, it never developed an external communication infrastructure. Although there was a Mergenthaler hot metal development group in England, the Monotype architecture was so different from the linecaster architecture that there was little utility in engaging in any know-how trading. This lack of absorptive capacity hurt the firm in future generations.

Table 8.5

Monotype: Integration of External Technological Knowledge

Year	Product	Absorptive Capacity		External Knowledge Formally Accessed	Total Units Sold*
		Prior related knowledge (Own R&D)	External communication infrastructure		
Hot Metal Typesetting: Absorptive Capacity not developed					
		Yes	No		
1880-1960	Hot Metal	* high	* none	* none	15,000
Analog phototypesetting: Absorptive Capacity not developed					
		Yes	No		
1957	Monophoto Mark 2	* none	* none	* none	
1969	Monophoto Mark 5	* high	* none	* none	550 (Mark 2-5)
1969	Monophoto 600	* high	* none	* none	50
1973	Monophoto 400	* high	* none	* none	50
Laser imagesetting: absorptive capacity developed					
		Yes	Yes		
1976	Lasercomp	none	* none	* hired David Hedgeland to head up new development group	
1979 - 1987	Lasercomp enhancements	* high	* university ties	* none	1300 (all Lasercomp)

* estimate of cumulative sales through 1990

Monotype's failure to develop absorptive capacity in analog phototypesetting

As discussed in Chapter Six, Monotype's first series of analog phototypesetters, the Monophoto Mark 2 - Mark 5 were "imitation hot metal" machines and used the Monotype hot metal architecture. They were therefore mechanical machines with an optical subsystem. As a result, Monotype, like Intertype, developed a large stock of knowledge in the optical engineering and lens design but none in electronics. In addition, since the Monophoto's internally focused hot metal group was doing the development, there was little interaction with external sources of knowledge and no development of a communication infrastructure.

In the mid-1960's while the rest of the industry was developing electro-mechanical machines, Monotype, was not even investing in electronics. The lack of absorptive capacity combined with no external communication infrastructure made the firm myopic in terms of recognizing the importance of new technology. One Monotype employee from 1963 - 1967 made an attempt to increase the firm's awareness of external technology and in a 1994 interview commented, "I became a one-eyed man in a blind kingdom." Frustrated with his attempts to enlighten the "blind," he went to work for another firm.

When Monotype did finally develop an electro-mechanical machine, the Monophoto 400 in 1969, it was not technically competitive with other machines on the market. The firm did not explicitly involve external sources and given the lack of external communication infrastructure, its ability to informally access external knowledge was limited. It is not surprising that the resulting machine performed poorly. After the Monophoto 600, the development group took a step backward and developed a machine that once more incorporated elements from the hot metal architecture. This machine, the Monophoto 400 was described as, "an odd amalgam of mechanics, fluidics and electronics... with anachronistic technical concepts which ran counter to prevailing development trends." (Wallis, 1990, p.4)

Monotype's failure to develop absorptive capacity in CRT technology

Monotype's lack of an external communication infrastructure also hurt it in terms of recognizing the significance of CRT technology. While the rest of the industry was beginning to invest in CRT technology, Monotype was continuing to work on the prior generation. Ronald McIntosh and Peter Purdy, inventors of the Linoton 505 (acquired by Mergenthaler as part of K.S. Paul) had originally approached Monotype with their technology. They had received a research grant from the British government, and if they sold the technology to a foreign firm, the grant would have to be repaid, so they were looking for a UK buyer. Mr. McIntosh stated in an interview that he was so appalled by the reply of Mr. J. Matson, president of Monotype, that he wrote it down on a sheet of paper which he had kept all these years. "We see nothing that will equal the excellence of our product in the next 25 years," was what Mr. Matson told the two inventors. Monotype was clearly not interested in what they had to offer. In the end Monotype failed to invest in the CRT generation.

Monotype's development of absorptive capacity in laser imagesetting

By the mid 1970's Monotype was experiencing a financial crisis. Its market share of phototypesetters was extremely low, and hot metal sales could no longer sustain the firm. Drastic measures were necessary, and so the firm finally looked outside for technology. Monotype was lucky to find David Hedgeland, an inventor who had been working on laser applications in the graphic arts. They hired him and he built a development group comprised of other outsiders to work on a laser imagesetter. The group was based in Cambridge (England) as opposed to Salfords where the rest of the Monotype organization was housed. The resulting Lasercomp was a major technical accomplishment and the first laser imagesetter in the industry.

Hedgeland also changed the company's attitude towards external technology. His development group was much more integrated with the external technical community, including ties to the academic community in Cambridge. Monotype thus developed absorptive capacity in the laser generation through both internal investments in R&D and ongoing communication linkages.

Despite its successful technical accomplishment, Monotype's commercial recovery was slow and the British government's National Enterprise Board had to organize a rescue plan in 1978. Monotype managed to survive the crisis, and in the end the Lasercomp did reasonably well, with almost a 10% share of laser imagesetters. As discussed in Chapter Four, however, the laser imagesetter generation did not last very long. With the advent of Postscript and stronger price competition Monotype's fortunes have continued to wane.

Compugraphic

Compugraphic was the most successful of the new entrants in the second generation of technology, analog phototypesetting. The firm was founded in 1960 by two individuals with a great deal of experience in phototypesetting: William W. Garth, Jr., ex-president of Photon, and Ellis P. Hansen, ex-chief engineer at Photon.[6] Compugraphic was not only successful in its initial entry, but successfully made the transitions to CRT and laser generations. Table 8.6 outlines Compugraphic's major product developments and serves as a reference for the following discussion.

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[6] See Chapter Four for a detailed discussion of Photon, the first new entrant to the industry with an analog phototypesetter

Table 8.6

Compugraphic: Integration of External Technological Knowledge

Year	Product	Absorptive Capacity Prior related knowledge	Absorptive Capacity External communication infrastructure	External Knowledge Formally Accessed	Total Units Sold*
Analog phototypesetting: absorptive capacity developed					
1968	CG 2961/4961	* high	* relationships with buyers, suppliers * ongoing university consultation * ongoing conference attendance / know-how trading	* George Sausele	5,900
1971	Compuwriter	* high	* same as above	* none	17,200
1977	Editwriter	* high	* same as above	* none	13,500
Digital CRT phototypesetting: absorptive capacity developed					
1973	Videosetter	* none	* none	* consulting from Washburn Labs	1000
1981	CG 8400	* high	* same as CG 2961	* none	11,500
Laser imagesetting: absorptive capacity developed					
1986	CG 9600	* none	* same as CG 2961	* none	1700
1987	CG 9400	* high	* same as CG 2961	* none	3400

* estimate of cumulative sales through 1990

Compugraphic's development of absorptive capacity in phototypesetting

From its inception Compugraphic had a strong culture of acquiring external technology. Colleagues who worked with Ellis Hansen, the technical director, described him as constantly looking outside the firm for new product ideas. "He had the opposite of the NIH [not invented here] syndrome," commented one of his employees in a 1994 interview. In fact, the idea for Compugraphic's first typesetter originated outside the firm. When George Sauselle, an outsider approached Hansen with the basic concept for a low-cost typesetter, Hansen liked it, hired him and formed a development team around him. The resulting 2961/4961 typesetters revolutionized the industry and were highly successful.

Hansen also created formal mechanisms to encourage outside interaction. Engineers were required to man the service help desks and frequently visit customer locations in order to understand customer needs. The firm's location near Boston allowed for ongoing interaction with a multitude of university professors. Attendance at technical conferences and industry trade conferences was also encouraged. This high level of absorptive capacity was reflected in the quality of the firm's products, and Compugraphic dominated the analog phototypesetter generation of technology.

Compugraphic's development of absorptive capacity in CRT technology

Compugraphic's external linkages helped it to recognize and invest in the CRT generation. Since the firm did not have internal expertise, it looked for an outside source. A small company, Washburn Labs, run by an ex-employee of CBS Labs, Clayton Washburn, was hired as a consultant. Employees at Compugraphic were assigned to work with Washburn in the development of a CRT machine. Unlike Mergenthaler's collaboration with CBS Labs, in this collaboration, Compugraphic worked with the external experts and provided individuals with the necessary skills to learn: Compugraphic's primary technical leader was an electrical engineer - someone who could learn from Washburn. The development was done off-site and had a skunk-works flavor to it. While the resulting product, the Videosetter, was only a moderate success Compugraphic benefited from the project in that in learned about the new technology. Subsequent CRT machines, including the 8600 and 8400 were developed internally and were very successful.

Compugraphic's development of absorptive capacity in laser imagesetting

When the time came to invest in a laser imagesetter, Compugraphic was accustomed to building relationships with external technical sources. The firm did not explicitly look for a single outside source of knowledge in the laser imagesetter generation, but instead tapped multiple sources. Many hours were spent meeting with competing suppliers in order to understand the nuances of laser technology. A research report analyzing the development of the 9400 (Tatikanda & Rosenthal, 1990, p.10), one of Compugraphic's early laser machines, emphasized the reliance on external expertise:

> " To gain a better understanding of laser diodes, laser vendors such as Sharp were invited to provide insight into their product and how it might operate in the CG [Compugraphic] device. They assisted in research, sometimes in CG's design labs. Also, laser diode researchers at M.I.T. were contacted and these people provided assistance."

Since software expertise became more important in this generation, Compugraphic also began to integrate itself into the local Cambridge "Route 128" software community. This informal sourcing of external knowledge worked, and Compugraphic's first laser typesetter, the CG 9600 was quite successful as were the follow-on machines.

8.4 Discussion

8.4.1 The importance of absorptive capacity

As discussed earlier, firms that developed absorptive capacity in a particular new technology were more likely to do well in making the transition to that technology. The details of the case studies provide further support of the importance of absorptive capacity on a project by project basis. For instance, not having invested in CRT technology itself, Mergenthaler did not benefit from technology transfer in their collaboration with CBS. Similarly, Intertype did not benefit from its collaboration with Harris' central R&D lab. In contrast, Compugraphic did benefit from its collaboration with Washburn Labs in the development of a CRT typesetter and was able to successfully do subsequent development on its own.

Even firms that eventually developed absorptive capacity did not immediately integrate external knowledge and perform well. The first development projects of even successful firms, were generally mediocre, despite the attempt to integrate external knowledge. The initial investment, however, had the spillover benefit discussed by Cohen and Levinthal in that the prior related knowledge accumulated during initial developments helped the firm to absorb external knowledge in subsequent projects.

If one examines the series of projects in each generation for both Mergenthaler and Compugraphic, there is a clear upward trend in terms of the product's performance. Mergenthaler's initial foray into phototypesetting, the Linofilm was not very successful, but it helped to build absorptive capacity, and future products were more successful. A similar pattern emerges in the laser generation. While the Omnitech 2000, the first laser imagesetter was not very successful, Mergenthaler learned about the technology through working with the laser scanner experts, and subsequent developments were more successful.

Likewise, Compugraphic's first CRT machine, the Videosetter, had mediocre performance, but the firm learned from external sources, and future machines did well.

The case studies also clearly demonstrate that absorptive capacity comprises both prior related knowledge and an external communication infrastructure. The communication linkages by which external knowledge is transmitted cannot be assumed to exist. The contrast between Monotype and Mergenthaler in the transition from hot metal to analog phototypesetting provides an example. Despite internal investments in R&D, first in optical engineering and later in electronics, Monotype was not successful in absorbing external knowledge. The engineers had not engaged in ongoing relationships with outside sources and technology scanning was minimal. Mergenthaler, in contrast, both invested in the new technology and established outside contacts and was much more successful.

8.4.2 The effect of prior absorptive capacity

Given the importance of absorptive capacity, why do some firms invest in developing it whereas others don't? The answer lies in an examination of the role of prior absorptive capacity. Cohen and Levinthal raise the concern that absorptive capacity in a prior technology may actually inhibit the firm from developing it in a new technology. This result is premised on the dynamically self-reinforcing nature of investments in absorptive capacity. As noted earlier, "the firm needs to have some absorptive capacity already to value it." (p.138) In contrast, I find that the external communication infrastructure developed in one technological domain helps a firm to develop absorptive capacity in a new unrelated technology. There are two main sources of this effect.

Recognition of the new technology

One reason firms may not invest in developing absorptive capacity in a new technological domain is a lack of recognition. Firms may not recognize the importance of investing in absorptive capacity in an unrelated area given their lack or prior related knowledge in the area. I find that firms that had developed strong external linkages in a prior technology were still able to recognize unrelated, competence-destroying technologies and make initial investments despite a lack of prior related knowledge.

For example, with the exception of Monotype, all incumbent firms from the prior generation recognized the importance of CRT technology and invested in developing products. Ongoing technology scanning and other communication linkages provided incumbents an awareness of the new technology. In contrast, Monotype never developed strong external communication infrastructure in analog phototypesetting. Therefore, when the transition to CRT technology began, the firm was unable to recognize its significance and never even invested in the technology. By the time the firm recognized its folly, it had already missed the generation.

Experience in forming linkages eases the establishment of new linkages

An external communication infrastructure in a prior technology also helps in the development of a new infrastructure. First, the culture of the firm is externally oriented, so in a transition the firm anticipates acquiring technology from outside and immediately begins to set up linkages in the new technical domain. Scanning of patents and technical journals in the new area, for instance is established early on.

Second, experience in the mechanics of forming relationships helps to structure new relationships. For instance, the firm may have a ready template for forging new supplier relationships. In this sense, there is cumulative learning about external relationships that transcends technological generations. This cumulative learning cannot be immediately acquired and is another factor that helps explain the differences between firms in developing absorptive capacity in a new technological domain.

Compugraphic's transition to laser imagesetting provides an example of the rapid establishment of a new infrastructure. The firm was able to absorb external knowledge through a number of immediate informal relationships as opposed to setting up an explicit transfer. For instance, the firm quickly began sending engineers to computer industry / software conferences when the importance of software expertise became evident. Without its prior experience at establishing linkages, the firm would probably have been much slower. The firm also had ongoing links to the MIT technical community that it could leverage in identifying relevant laser experts. Prior relationships with academics provided a template for structuring new relationships, thus easing the process of establishing a new external network.

The contrast between Mergenthaler, Intertype and Monotype in the transition from hot metal to analog phototypesetting provides another example. Given their history of informal know-how trading, both Mergenthaler and Intertype were accustomed to finding valuable external technical knowledge. In their first phototypesetter developments, both firms therefore found external sources for the optical /lens subsystem and worked with those firms to develop expertise. Monotype, on the other hand, was both geographically and technologically isolated during the hot metal era and did not develop a culture used to looking for outside solutions. It therefore depended on its own internal engineers to develop the first phototypesetter, without any explicit external technology.

If development of a new external communication infrastructure benefits from prior experience and prior relationships, then how does a firm ever catch up to firms that possess such experience? There is some evidence that new hires, particularly new technical leaders can help a firm to "jump start" an external communication infrastructure. These individuals bring with them their own set of external contacts, and may already be tied into the relevant network. They may not possess a template for structuring relationships, but they certainly bring connections.

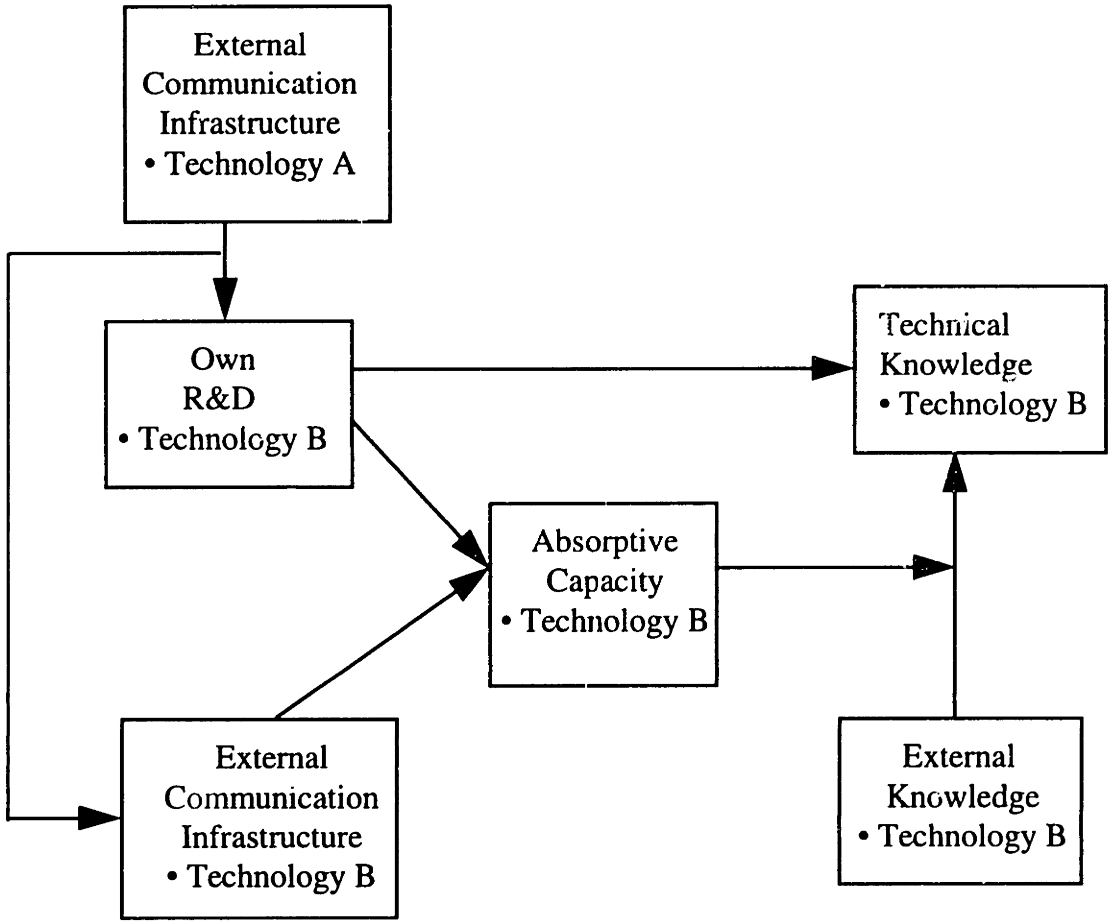
In its first electro-mechanical phototypesetter development, Mergenthaler hired a number of new employees with electronics expertise, including a new director of R&D with contacts at Columbia University. These ties were important in terms of establishing an external communication infrastructure. Likewise, when Monotype entered the laser generation it hired a new technical leader and a new team. The new leader had ties to Cambridge University, and located the development team in Cambridge to facilitate communication. In each of these cases, the firm was able to quickly establish and leverage external ties.

A revised model

Given that an external communication infrastructure can help both to encourage investment in the follow-on generation of technology as well as help with the development of a new external communication infrastructure, I propose the following additional modification to Cohen and Levinthal's model.

Figure 8.3

Sources of External Knowledge: a Revised Model



This modification implies that the development of an external communication infrastructure is even more important. The infrastructure not only contributes to absorptive capacity in the current technology, but helps in the development of absorptive capacity in a new technology.

8.5 Implications for future research

I started out asking how a firm could develop dynamic capabilities. Clearly investing in developing absorptive capacity is part of dynamic capabilities -- these case studies provide evidence about the importance of absorptive capacity in facilitating technological transitions. They also, however, raise a number of additional questions.

First, if a firm does begin to make internal investments in a competence-destroying technology, how should the development team for a new technology be integrated into the existing organization? Should they be physically co-located with individuals working on the prior generation, or kept separate. In these case studies we see three successful examples of the initial new development being geographically separated from the existing development organization: Compugraphic's first CRT machine and Mergenthaler and Monotype's first laser machines.

By keeping the new development group separate, the firm avoids having to change the existing organizational routines and procedures and doesn't risk having the new group "corrupted" by the existing group's way of thinking. The new group can also choose a location that optimizes its ability to form a strong external communication infrastructure. On the other hand, while there is generally some overlap between generations, the existing group must eventually change. Of these three examples, both Compugraphic and Mergenthaler brought subsequent development back to the main facility. Presumably once the "new" engineers had experienced a development projects they wouldn't be "corrupted" by the existing organization, and could help encourage change. Monotype, however, kept its laser development group separate, in Cambridge, in order to take advantage of local academic experts. There are also examples of successful transitions where the new development group was not initially kept separate

(Mergenthaler's first analog phototypesetter and Compugraphic's first laser imagesetter). In order to better understand the trade-offs involved in organizing for radically new technology and changing the internal organization's routines and procedures additional research is clearly needed.

Second, when should an incumbent simply acquire a firm with needed expertise instead of attempting to develop it internally? In some ways, acquisition seems a much easier way to gain new technical knowledge. Presumably the acquisition candidate possesses the knowledge, and once bought, the knowledge belongs to the company. Once more, there are trade-offs that need additional analysis. Evaluation of the technical capabilities of an acquisition candidate is not a trivial exercise. Once the firm has invested enough to be able to make an informed judgment about the candidate, it may well be able to develop the technical expertise internally. Second, integrating the external knowledge of the acquired company into the existing organization may be difficult. It should certainly be more difficult than reintegrating a product development group that was physically separated from the core company. The acquisition candidate has its own distinct culture and the trade press is replete with examples of failures to integrate acquisitions.

Having cautioned against acquisition, it clearly works in some cases. If a firm has gotten so far behind in a generation that it cannot catch up, acquisition may be the only viable option. Mergenthaler was quite successful in its acquisition of K.S. Paul. As a by-product of its collaboration with CBS, the firm had enough knowledge to evaluate K.S. Paul's technology. And since there was significant overlap between the analog phototypesetting and CRT generations, the firm could afford to let K.S. Paul continue with CRT developments and not immediately become integrated into the rest of the company. The US organization gradually began working with them, and the organizational disruptions were therefore minimized. Additional study of the importance of acquisitions in establishing dynamic capabilities would be welcomed.

Third, how does this framework apply to other industries? There is some evidence that external linkages played an important part in distinguishing between the ability of different pharmaceutical firms to develop biotechnology capability (Nicholls-Nixon, 1993). The advent of the "information superhighway" and the current flurry of alliances in telecommunications, computers, consumer electronics and entertainment and would lead one to believe that firms value external partners when faced with any type of uncertainty: technical, market, or regulatory. How should the management of external relationships aimed at acquiring technical knowledge differ from those that of relationships formed to gain market expertise?

Finally, what is the role of geographically distributed R&D locations in facilitating technological transitions? Mergenthaler had multiple R&D locations doing typesetter development and appears to have benefited in many ways. First, by being forced to communicate with the other Mergenthaler labs, each country lab got accustomed to looking outside for technology. They may have therefore been more willing to acknowledge the importance of external sources of technology. Second, a sense of internal competition among the US, UK, and German development groups spurred innovation. Interviews with developers from each country made clear that each group had a strong sense of pride, and wanted to demonstrate its superiority. Third, by developing different generations of technology in different locations, Mergenthaler was able to overcome some of the organizational inertia which hinders many transitions. For instance, as discussed above, while the US development group focused on analog phototypesetter development, K.S. Paul, the acquired firm focused on CRT development. Finally, the firm was able to leverage different country institutional environments. Burgelman (1994) points out the importance of intraorganizational evolutionary processes to firm survival, and identifies the need for internal variation, followed by selection and retention. By operating in multiple environments, Mergenthaler had build in variation. Once more, this area provides fruitful ground for further exploration.

Chapter Nine

Discussion and Conclusions

9.1 Summary of Results

The innovation literature is replete with examples of incumbent failure in the face of competence-destroying technological change. A great deal of research has analyzed the reasons for this failure, with much less emphasis placed on examining incumbent success, despite the fact that such success is not that uncommon. The primary contribution of this dissertation is to provide a clearer understanding of how incumbents can survive and prosper in the face of competence-destroying technological change.

Incumbent performance is examined through an analysis of over 100 years of history in the typesetter industry. The typesetter industry began in 1886 with the invention of the Linotype machine by Ottmar Mergenthaler. After almost seventy years of incremental change to the basic Linotype architecture, the industry was shaken by four waves of technology. Unlike the pattern observed in other industries, however, typesetter incumbents were sometimes successful in making the transition to a new generation of technology. This dissertation explores the reasons why.

First, superior technical performance was not found to be responsible for incumbent success. Consistent with prior research (Tushman & Anderson, 1986, Henderson & Clark, 1990) there is evidence of a technological disadvantage faced by incumbents when developing products in a competence-destroying generation of technology. Despite comparable investments, the initial products developed by incumbents were technically inferior to those developed by new entrants. An in-depth examination of specific development projects showed that when an incumbent developed a product in the new generation, it was handicapped by its prior experience. Its approach to the new technology was shaped by its experience in the prior technology, with elements of the prior generation's architecture often present in the new products.

Although competence-destroying shifts hurt the relative technical performance of incumbents' products, they did not necessarily encourage entry and result in a loss of market share; incumbents sometimes prospered despite their technical disadvantage. By utilizing a theoretical lens that isolates the effect of a technological shift on an incumbent's current competence as opposed to its effect on other barriers to entry, unrelated to current competence, a clearer picture of this success emerges. Descriptive statistics as well as quantitative models of entry and market share showed that barriers unrelated to current competence, such as a strong reputation and sunk cost investments in a large font library, provided incumbents a buffer from competition, deterring entry and enabling incumbents to prosper despite their technical disadvantage. Only when both current competence and other barriers to entry were destroyed did incumbents suffer significantly in the market.

By disentangling the effect of destroying current competence vs. other barriers to entry, the dangers of considering only a single perspective are also demonstrated. Examining the effect of competence destruction on entry and market share without controlling for other barriers gave misleading results. Once other barriers to entry were controlled for, effects assumed to be the result of competence destruction were actually found to be the result of destroying other barriers to entry. Including both perspectives is therefore crucial.

This framework is also useful in that it helps to synthesize other findings regarding the survival of incumbents faced with competence-destroying technological change. As discussed in Chapter Two, one can think about many of the explanatory factors described in other empirical work (e.g. Afuah, 1994; Mitchell, 1992; Rosenbloom & Christensen, 1994) in terms of barriers to entry. Control over limited distribution channels, a strong reputation with established customers and customer switching costs are all barriers that can remain strong despite the destruction of current competence.

Incumbents must eventually develop new capability, however, and they do not always have the luxury of a competitive buffer, so I also examine how established firms were best able to make technological transitions. In other words, how did "dynamic capabilities...the capacity of a firm to renew, augment, and adapt its core competencies over time" (Teece, Pisano & Scheun, 1992, p.18) manifest themselves.

Through exploratory case studies of four firms, one critical factor emerges: the ability to identify and integrate external knowledge in a new technological domain. In other words, firms that develop new "absorptive capacity," (Cohen and Levinthal, 1990) are more likely to survive a technological shift. While Cohen and Levinthal focus on internal R&D investments as the primary element of absorptive capacity, a second important component is identified here: an external communication infrastructure to facilitate the transmission of external information. An external communication infrastructure comprises formal technology scanning, individual know-how trading relationships between engineers, and relationships with suppliers, users and universities.

Creation of an external communication infrastructure in the current generation of technology was key to developing both elements of absorptive capacity in the next generation. By systematically scanning the external environment and developing relationships with external experts firms were more likely to become aware of the next generation of technology and invest. In addition, building a new external communication infrastructure was facilitated by the experience of having built one in the prior generation. Firms had learned to structure external relationships and establishing new relationships was therefore easier.

9.2 Implications for theory and managerial practice

This research clearly demonstrates the need to consider both organizational differences and economic competition in order to understand firm performance. By examining only the differing technological capabilities of incumbents and new entrants without considering the economic effect of other barriers to entry, one obtains an incomplete picture of the competitive implications of radical technological change. While new entrants may have superior technological capabilities, incumbents may benefit from the economic effect of other barriers to entry. In the typesetter industry, incumbent sunk cost investments in a font library as well as strong reputation advantages were able to protect the incumbents from the effects of competence-destroying technology.

While this dissertation examined the typesetter industry, it has salient implications for other industries. In any industry where established firms are threatened by technological change, incumbents can attempt to protect themselves from competition by investing in barriers to entry that will transcend the shift. For instance, pre-emptive advertising investments to maintain a brand image, or long-term contracts with key distributors can help to ward off new entrants. In fact, such pre-emptive investments may make sense, not only when firms face a potential technological disadvantage, but when they face other environmental shocks. For instance, there is evidence that when pharmaceutical firms faced the approval of generic versions of their drugs, they pre-emptively invested in advertising in order to deter entry (Scott-Morton, 1994).

Ironically, when industries are undergoing periods of technological turbulence, management's immediate inclination might be to shift more resources to R&D and less resources to advertising and other "soft" investments. Concerned with their firm's ability to develop new technological capability, management may perceive that more R&D investment will help to more effectively compete with potential new entrants. This research implies that such a shift in resources may be inappropriate. By instead, continuing to invest in advertising and other reputation-enhancing factors, the firm may actually be better off in that it will buy itself more time to develop new capabilities.

The importance of identifying and integrating external technological information also has important implications for both theory and practice. Prior work (Cohen & Levinthal, 1990; Cohen & Levinthal, 1994) has modeled absorptive capacity, emphasizing the dynamically self-reinforcing nature of internal investments in R&D. In contrast, the additional component of absorptive capacity identified in this work -- an external communication infrastructure -- is not dynamically self-reinforcing, but instead, actually helps to develop absorptive capacity in a new technological domain. Knowledge about how to manage external relationships cumulates and is applicable across generations of technology. Modeling that contrasts these two processes, the cumulation of knowledge through internal R&D and the cumulation of knowledge about managing relationships should yield prove fruitful.

Interestingly, while managers most often look to external sources of knowledge during periods of radical technological change, this research implies that investments in an external communication during periods of incremental change are critical. While engaging in external relationships during a period of relative strength may seem counterintuitive, by establishing a network of relationships, a firm can develop a new network much more quickly when faced with a radical technological shift.

9.3 Suggestions for future research

While this work takes an important first step towards understanding incumbent performance in the face of technological change, much work remains. Some of the measures in this paper move beyond the usual one / zero classifications of technological change, but additional work on improved ways to measure the effect of shifts in technology would be welcome. In particular, improved measures of competence and competence destruction are needed. For instance, the "Skill Loss" measure used in this work captures the change in component knowledge, but it does not begin to capture the change in architectural knowledge associated with a shift. One interesting way to understand and measure an organization's shifting architectural knowledge might be to measure communication flows in a manner similar to much of Tom Allen's work (1984). By understanding how the structure of the communication network shifts over time, one might gain a clearer understanding of how architectural shifts affect organizations and how a firm might best adjust to them.

Further exploration of the value of distributed R&D is also warranted. While this strategy was useful to one firm in this study, it was not utilized extensively by others. Theoretical work examining the trade-offs involved in distributed R&D could help to clarify in which situations it is appropriate. A broader empirical study that examined the utility of distributed R&D across a number of industries would also help to shed light on the topic. How important is it, for instance that distributed sites be located in different institutional settings?

The location, organization and staffing of initial development projects in a new technology is another area for future exploration. Should new technology development be co-located with product development in the prior generation? Should team members be organizationally part of the same group as those working on the prior generation? This research provides preliminary evidence that the first new development should be both physically and organizationally distinct, however additional confirmatory work is necessary. In addition, while the initial project may be separate, at some point, new developers must be integrated into the existing organization. Optimal timing and methods for accomplishing this integration warrant further study. Finally, new development projects in this study were staffed by a combination of newly hired engineers with new skills, and existing engineers who had been retrained. The trade-off between retraining existing employees and hiring new ones also warrants further study.

The optimal way for a firm to adapt given a changing external environment can vary. This work has focused on situations where most firms wanted to continue producing the same products, and it has attempted to identify ways to develop new technological capability within the given product domain. In some cases, however, a firm may decide that the transformation it needs to make is to stop producing a given product or serving an existing customer base and instead diversify into a totally different area. While some work has been done to explore how firms accomplish this type of transition (Rosenbloom, 1982; Burgelman, 1991, 1994), extensions would be useful. It would be interesting to see if some of the same mechanisms useful in the present context can also help under alternative situations. How, for instance does a firm develop absorptive capacity in not only a totally new technology but a totally new market?

While the focus of this dissertation has been on understanding incumbent performance, some interesting preliminary findings about new entrant success also emerge. Even in technological generations where new entrants were "successful," it was a handful of firms that experienced that success. The majority of new entrants in all new generations of technology failed. Since new entrants presumably anticipate making money when they decide to enter, it would be interesting to understand why the vast majority appear to have miscalculated when estimating post-entry profitability. What is the source of their error, and are there systematic differences between entrants that successfully exploit technological discontinuities as opposed to those that fail?

A final extension of this work would be an integration of the disparate organizational and economic literatures on industry entry/exit patterns. Whereas a great deal of the population ecology literature (e.g. Hannan & Freeman, 1977,1984,1989; Carroll,1988; Barnett & Carroll, 1987; Haveman, 1992,1993) has emphasized the importance of density-dependent legitimation and competition in driving entry into an industry, little of this work has taken into account more traditional economic barriers to entry. Likewise, most of the empirical work measuring economic barriers to entry and analyzing entry/exit patterns (e.g. Goreki, 1975; Dunne, Roberts & Samuleson, 1988,1989; Gort & Klepper, 1982; Klepper & Grady, 1990) does not consider density dependence. By considering the effects of both factors, this paper takes an important first step towards relating these two bodies of work.

9.4 Conclusion

In an era of increasingly rapid technological change, it is important to understand how established firms can prosper when emerging technologies transform their industries. By studying the historical industry dynamics resulting from technological change in the typesetter industry, this dissertation has helped to identify some systematic patterns and provides guidance for managers. Investments in maintaining barriers to entry that will be unaffected by technological change can help incumbents to survive despite the competence-destroying nature of a shift. In addition, building structures for the integration of external knowledge in the current generation, can help to identify the need for investment in future generations as well as facilitate the integration of external knowledge through establishment of new external relationships. Continued work in this vein is welcome.

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Trade Journals

American Printer
British Printer
CIS Newsletter
Editor & Publisher
Graphic Arts Monthly
Inland Printer
Journal of Typographic Research
Monotype Recorder
Printing & Publishing
Publish
Seybold Report
Typeworld

Annual Reports / 10Ks

Adobe Systems, Inc.
American Type Founders, Inc.
Adressograph-Multigraph, AM International
Compugraphic
Dymo Industries, Inc.
Fairchild Camera & Instrument
Intertype Corporation, Harris-Intertype Corporation
Itek Corporation
Lanston Monotype Machine Company
Mergenthaler Linotype Company, Eltra Corporation, Allied Chemical Corporation, Allied Corporation, Linotype-Hell AG
Photon, Inc.
Volt Information Sciences (Autologic)

Archival Material

- Graphic Arts Research Foundation Archives
  - Reports to the subscribers of the Graphic Arts Research Foundation
  - Newspaper clippings about the Photon machine
  - L. Moyroud speech notes
- Rochester Institute of Technology, Cary Library Sauselle Archives
  - Newspaper clippings about the typesetter industry
  - Alphanumeric/Autologic Offering Memorandum
  - Various manufacturer's product description literature
- Linotype-Hell Company Archives
  - Linotype Bulletin, Linotype News and Linotopix, various issues
  - Product descriptions: promotional literature, technical manuals
  - Strategic plans
  - Organization charts
  - Newspaper and journal clippings
- Agfa Compugraphic Library / Archives
  - Product descriptions: promotional literature, technical manuals
  - Strategic plans
  - Organization charts
- Personal archives of G. Brett, H. Klepper, R. McIntosh, F. Romano, F. Szabo and L. Wallis
  - Product descriptions: promotional literature, technical plans
  - Strategic plans
  - Organization charts
  - Newspaper and journal clippings

Appendix A

Interviewees

Interviewee	Organization(s)	Position(s)
Adams, Richard	Graphic Arts Technical Foundation (GATF)	Color Specialist
Allen, Mitch	Compugraphic Apple	Engineering
Benevento, Frank	GATF	Manager Technical Information Group
Brassell, Morgan	LA Times	Manager Technical Development
Brett, Geoffrey	Linotype-Paul	UK Director R&D
Byers, Steve	Mergenthaler Linotype	US VP Typography
Carter, Matthew	Crossfield Mergenthaler Linotype Bitstream Carter & Cone	Type Designer
Cavenaugh, Mike	Mergenthaler Linotype	US Sales Representative
Chisholm, Paul	Mergenthaler Linotype	US Sales Representative US VP Sales & Marketing
Cone, Cherie	Mergenthaler Linotype	
	Bitstream	Type Designer
	Carter & Cone	
Corrado, Vic	Mergenthaler Linotype	US VP Systems & Planning
Dantas, Carl	Compugraphic	President & CEO
Dunn, Thomas	Dunn Technologies	Industry Consultant
Eastman, Brian G.	Compugraphic	Engineering
	Quadex	
	Gerber Systems Corporation	President & CEO

Interviewee	Organization(s)	Position(s)
Eichler, Howard	Newspaper Association of America	VP Technology and Consulting
Falconi, Stefano	Harvard University	Manager, Computer Systems and Desktop Publishing
Forgione, Rick	Raytheon	Desktop Publishing
Gable, Jim	Apple	Truetype Product Manager
Garth, William Jr.	Graphic Arts Research Foundation	Son of Photon and Compugraphic Founder
Givins, Robert	Compugraphic	VP Typography
Goble, Corban G.	W. Kentucky University	Professor of Journalism History
Goodstein, David	Interconsult	Graphic Arts Consultant
Goulet, Ron	Compugraphic Gerber Systems Corporation	Engineering VP Engineering
Greene, Robert	Compugraphic Adobe Systems	Product Management
Hagen, Thomas	Camex	Founder
Halleran, Larry	Compugraphic	Marketing Manager Image Processing
Hansen, Walter	Mergenthaler Linotype Ultre	Engineering Program Manager Co-Founder
Hines, Art	AM Varityper	Product Planning
Kayson, Carl	AM International	Member, Board of Directors
Keller, J.A.	Mergenthaler Linotype	President & CEO
Kleper, Michael	Rochester Institute of Technology	Professor of Graphic Arts

Interviewee	Organization(s)	Position(s)
Klepper, Herbert	Mergenthaler Linotype Ultre	Manager Product Engineering Co-Founder
Klipell, David	Mergenthaler Linotype	US Product Manager Imagesetters
Kyte, Derek	Linotype-Paul Chelgraph	UK VP R&D Founder
Kyte, Jill	Adobe Systems	Postscript Product Manager
LeCompte, Charles	Hardcopy Observer	Editor
Lewis, Robert	InfoCom	Founder
Marshall, Alan	Lyon Printing Museum	Ph.D. on Photon
McIntosh, Ronald	Linotype Paul Purdy-McIntosh	UK Co-inventor of L505 Co-founder / engineer
Morgan, Grant	Compugraphic Bobst/Varisystems Dymo Photon	VP R&D
Murphy, Henry	Mergenthaler Linotype	US Sales Rep US VP Sales & Mktg
Perry, Tony	Harris Publishing Systems	VP Sales
Pick, George	AM Varityper	VP R&D
Quick, Vikki	Hyphen, Ltd.	Marketing
Rancatore, John	Compugraphic	Type Design Manager
Randall, Keith	Atex	Marketing Manager
Renwick, Dick	Compugraphic Photon	VP Manufacturing Operations Engineering

Interviewee	Organization(s)	Position(s)
Romano, Frank	Rochester Institute of Technology Datek, GAMA Mergenthaler Linotype Compugraphic	Lecturer in Graphic Arts Industry Consultant Marketing
Szabo, Frank	AM Varityper	Manager Opto-Mechanical Engineering
Wallis, Lawrence	AM Varityper Crossfield Monotype	European VP Sales
Webb, Joseph		Industry Consultant
Webster, Thad	Hewlett Packard	Laser printer Product Manager
Weiss, Michael	Weiss and Associates	Industry Consultant
Windell, John	State Street Consultants Compugraphic	Industry Consultant Marketing
Woodcam, Donna	Compugraphic	Type Manager
Wyle, Don	Compugraphic	VP Human Resources VP Type Division
Zarwan, John	State Street Consultants Compugraphic	Industry Consultant Marketing
Zayre, Rick	IBM	Font Specialist

Appendix B

Sample Data Request and Correspondence

- Data "wish list"
- Letter to Jack A. Keller ex-President / CEO Mergenthaler Linotype
- Letter to Derek Kyte ex-Technical Director of Linotype-Paul (K.S. Paul)
- Letter to Frank Szabo, ex-VP opto-mechanical engineering AM Varityper
- Letter to Carl Dantis, ex-President / CEO Compugraphic

Dissertation on Technological Evolution in the Typesetter Industry:
Data "wish list"

I am tracking the industry from the inception of hot metal typesetting in 1886 through 1990. Where possible I would like the following information for that whole time period.

Industry-level data

- Industry Sales
  - total sales - both unit and dollar sales
  - sales by geographic segment
  - sales by buyer segment (e.g. newspaper, magazine, service bureau)
- A complete population of firms in the industry, including year of entry, exit, and merger or acquisition (for the US and Europe).
- Market share of major players (for the US and Europe)
- For each new technological generation
  - Date of first product introduction
  - Background of first firm to introduce a product
  - Performance measures comparing this generation to the previous one

Customer Data

- Rate of adoption of each new technological generation
  - What switching costs were associated with adoption?
  - Which segment of customers adopted first?
- Main buyer purchase criteria and how the criteria shift over time

Firm-level data

Performance

- Annual Reports / Financials -- Sales, R&D expenditures, Profit
- Patent filings
- Sales in related businesses (type foundries, printers)

Organization

- Years in which the CEO / top management team changed
- Organizational structure -- how did marketing, R&D and manufacturing relate
- Number of employees in sales, R&D, and manufacturing
- Collaborative relationships with other firms

Firm Product-level data

- A complete list of new product development efforts
- Unit sales of each product (cumulative and over time where possible)
- Product price and performance characteristics
- For each major product development effort
  - Start and end date
  - Number and location of employees on the team
  - Background of employees (e.g. mechanical engineer, electrical engineer, computer scientist)

July 22, 1994

Mr Jack A. Keller

Dear Mr. Keller,

Thank you very much for agreeing to speak with me next week. As a basis for our discussion, I have enclosed an abstract of my Ph.D. dissertation and some summary information I have compiled on Mergenthaler's product announcements over time. Basically I am hoping you can help me understand how Mergenthaler survived so many technological shifts when other firms in the industry failed to. I'd like to address the following questions.

Industry Issues

Approximately what share of hot metal sales did Mergenthaler have throughout the late 40's and 1950's? I was told by one individual that Intertype actually started to dominate the hot metal market and had a higher share than Mergenthaler, but have found no confirmation of that.

To what do you attribute the lack of entry into the typesetter industry during the hot metal era ?

- Given the size of the market and the minimum efficient plant size, there wasn't room for an additional player.
- Given how far down the production learning curve Mergenthaler and Intertype were, other firms couldn't be cost competitive
- Product technology was proprietary (patents / trade secrets)
- The cost of developing a font library was too high
- Customer loyalty to the existing players was high

What changed with the advent of phototypesetting that allowed so many firms to enter the industry?

- New entrants (e.g. Photon) had a technological lead
- Incumbent firms weren't investing heavily enough in the technology
- Incumbent firms were less effective at developing the technology since they were tied to hot metal
- The minimum efficient plant size decreased, thus supporting more players in the industry

At what point did phototypesetter sales exceed hot metal sales for the industry?

Mergenthaler

How did Mergenthaler make the initial decision to invest in phototypesetting development?

- How were resource allocation decisions made? Who influenced those decisions?
- When did phototypesetting product development begin? At what point did it become clear that phototypesetting would eventually supplant hot metal?
- The Elektron and the Linofilm were under development at the same time? What was the relative allocation of development resources to each? In retrospect would you change that allocation?
- Did you ever consider the option of acquiring the technology as opposed to developing it in-house?

Which organizational strengths, or competencies of Mergenthaler were still valuable after the shift from hot metal to phototypesetting? Which became obsolete?

What organizational changes were made to accommodate the shift away from hot metal?

- Was new management brought in?
- Was the engineering / product development group restructured?

Why was all CRT development (other than the 1010) done in the UK? Why was CRT expertise acquired, whereas phototypesetting expertise was developed in-house?

When did the German company begin doing product development? Did the US, UK and German development groups compete for resources? Was there cooperative development?

Where might I historical financial data?

- Moody's has Mergenthaler data up until Eltra was formed, but from that point on, Mergenthaler is not broken out. Might you have records of Mergenthaler's numbers or know where I might find them?

Finally, in your opinion, why was Mergenthaler more successful than Intertype or Monotype (even in the UK market) in making the transition from hot metal to phototypesetting?

Thank you in advance for your assistance. I understand that I am asking you to remember things from 40-plus years ago, so I don't expect you'll recall precise numbers and dates, but your general impressions would still be helpful. I appreciate your taking the time to discuss Mergenthaler's history with me. I will see you on Wednesday, July 27 at about 10:00.

August 1, 1994

Mr. Derek Kyte

Dear Mr. Kyte,

I am a Ph.D. student at the Massachusetts Institute of Technology Sloan School of Management and am writing my dissertation on how firms in the typesetter industry have survived the technological transitions of the last century. Both Lawrence Wallis and Jack Keller gave me your name as someone intimately familiar with the technological changes in the industry. I was hoping that you might be able to help me out in my data collection efforts. I think there are three ways you might be able to help:

First, given your experience at Mergenthaler, I would like to get your perspective on how Mergenthaler's international R&D organizations actually functioned.

- After K.S. Paul was acquired, my understanding is that there was product development going on in the US, UK, and Germany. I want to understand how R&D/product development was distributed among these organizations. Which products were developed in which locations? How large were the engineering staffs at each location? How did this change over time? How much cooperation between locations took place?

- How were resources allocated among the R&D organizations? Did they compete for resources? Who decided how much each organization received?

- How were product specifications agreed upon? Were different models often needed for different international markets? Was there a structure in place to capture input from marketing/sales?

Second, as a founder of Chelgraph, I wanted your perspective on the "PDL wars" of the mid-80's among Postscript, Interpress, DDL and ACE.

- Did you develop ACE with the goal of becoming the industry standard?

- Was Postscript more successful in the imagesetter industry simply because of its desktop publishing presence? What other factors influenced its predominance?

Third, I would like your perspective on why so many firms that attempted to enter the typesetter/imagesetter exited without success (e.g. Bobst, Crossfield, Dr. Boger's Copytronic in 1975, Fairchild, Rockwell MGD Graphic Systems, Singer, Sun Chemical). What differentiated the more successful firms such as Compugraphic, AM Varityper, and Autologic?

Finally, I have enclosed a "wish list" of data I am attempting to gather. I understand that much of this information will be impossible to come by, but I would appreciate any assistance you might be able to give me in finding it. I am especially interested in getting market share data for Europe as opposed to the US.

I plan on visiting the UK the week of September 12, and wonder if there might be a convenient time to meet with you. Please drop me a note with a phone number where I might reach you, or give me a call at (617) 253-0286 and I will call you back. Thank you for your help, and I look forward speaking with you.

Best regards,

Mary Tripsas

July 13, 1994

Mr. Frank Szabo

Dear Mr. Szabo,

Thank you very much for agreeing to meet with me next week. I have enclosed an abstract of my Ph.D. dissertation as well as some summary information I have compiled on Varityper's product announcements over time in order to have a base to work from. I was hoping you could assist me in the following ways.

First, as someone familiar with multiple technological generations of typesetting, I would like to get your opinion on how "radical" different innovations in the industry were. By "radical" I mean how difficult was it for firms already in the industry to develop products which incorporated these technologies. Did they require a new set of capabilities? Did engineers need retraining? Were technical experts hired or brought in as consultants? Were technologies licensed? Were firms with expertise acquired? Alliances formed? The innovations which I am interested include the following:

Typesetters
(1) Slave phototypesetting machines which used light to expose letters stored on film and were driven by justified paper tape which had proprietary codes
(2) Incorporation of the ability to drive the machine with TTS codes
(3) Incorporation of hard-wired logic into (1) or (2) in order to do hyphenation and justification
(4) Substitution of hard-wired logic with a programmable minicomputer
(5) Use of a CRT instead of light to expose letter stored on film
(6) Digital storage of letters as "start and stop" points for vertical strokes of a CRT
(7) Digital storage of letters as straight-line outlines instead of "start/stop" points
(8) Use of laser instead of a CRT
(9) Use of a laser and a proprietary raster image processor (RIP)
(10) Incorporation of a Postscript RIP
(11) Plain paper instead of photographic output

Front end systems to drive a typesetter
(1) Justifying keyboards
(2) Batch systems for computerized typesetting
(2) Single user video display units with text editing capabilities
(3) Multiuser front-end systems with text editing capabilities
(4) Front-end systems for editing both text and graphics

Also, how strong was the patent protection of different technologies? Did some firms tend to patent more than others?

Second , I would like to understand how Varityper's R&D/product development efforts evolved over time.

* Who made the decision to license the first phototypesetter, the AM 725, from Photon as opposed to developing in internally? What factors influenced the decision?
* How did AM develop the expertise to design and manufacture the AM 748, the first internally developed phototypesetter? Was there an explicit effort to transfer product development and manufacturing technology from Photon?

* Did any of the strike-on product developers work on the phototypesetters? If not, what happened to them? How were resources allocated between strike-on and phototypesetter development?

* How was expertise in CRT and laser technologies developed in the 70s and 80s?

* How large was the R&D organization in the 50's? 60's? 70's? 80's?

* How was the R&D organization structured over time? By project, by functional area, or as a matrix organization?

* How were product specifications defined for a development project ? Did engineering or sales/marketing spec the product? How did the relationship between sales/marketing and engineering change over time?

* Was the research and development group at Varityper separate from the rest of AM, or did central R&D play a major role in product development? The 1961 Annual Report says "Work of research and development groups at subsidiary companies, such as Varityper Corporation, is integrated with over-all corporate programs to complement central research conducted at Cleveland." Was that wishful thinking? Did it change over time?

* In 1963, AM established a separate Market Research and Product Planning group headed by Clarence Margach. Did this group also address Varityper's markets and products? How was their relationship to Research and Engineering (headed by Albert Mignone) structured?

* In addition to product development projects which resulted in products, what failed product development projects can you recall?

Third, do you recall how Varityper's market position shifted over time?

* Approximately what share of strike-on sales did Varityper have over time? At what point did Varityper's phototypesetter sales overtake strike-on sales?

* What was Varityper's phototypesetter market share from 1970 - 1990? How does this share vary by segment? (The 1979 annual report stated that AM Varityper accounted for approximately 40% of the in-house market)

Thank you in advance for your assistance. I understand that I am asking you to remember things from 40-plus years ago, so I don't expect you'll recall precise numbers and dates, but your general impressions would still be helpful. I will call you Friday to confirm a time to meet, but let's tentatively say Tuesday the 19th in the morning perhaps continuing into the afternoon. I appreciate your taking the time to discuss your experiences and Varityper's history with me.

Best regards,

Mary Tripsas

August 8, 1994

Mr. Carl Dantis

Dear Mr. Dantis,

Thank you very much for agreeing to speak with me in the next few weeks. It turns out that I will be out of town from August 11-21, so ideally I would like to get together soon after that. I will still call you on August 10 to discuss what might work.

As a basis for our discussion, I have enclosed an abstract of my Ph.D. dissertation and some summary information I have compiled on Compugraphic's product announcements over time. As someone familiar with the early days of both Photon and Compugraphic, your perspective is especially valuable to me. Basically I am hoping you can help me understand what factors contributed to Compugraphic's successful entry into the industry - especially given what, at the time, must have seemed formidable competitors. I'd like to address the following issues.

Compugraphic

Initial success

- To what extent were product technologies developed in-house as opposed to acquired? Was there an explicit effort to find external sources?

- How did management deal with the rapid growth of the company? Many entrepreneurial firms run into problems when they reach 200+ employees and have to bring in "professional" management. At Compugraphic, however, the original management team managed to do quite well. What do you think enabled you to overcome the traditional obstacles faced by start-ups?

The transition to CRT typesetting

The transition from photographic typesetting to CRT typesetting was difficult for many firms in the industry. Mergenthaler ended up acquiring a firm to get access to the technology. Berthold acquired both Alphatype and Guttinger in an attempt to get access to a competitive CRT product. Monotype and Photon missed the whole CRT generation. Compugraphic, however appeared to make the initial transition with minimal disruption. What factors contributed to this?

- How did Compugraphic make the decision to invest in CRT phototypesetting development at the time it did?

- The first CRT machine, the Videosetter, was under development at the same time as the Compuwriter. What was the relative allocation of development resources to each? In retrospect would you change that allocation?

- How were resource allocation decisions made? Who influenced those decisions?

- Did you ever consider the option of acquiring CRT technology, as Mergenthaler did, versus developing it in-house? How was in-house CRT expertise established?

- Despite being relatively early with a CRT machine, Compugraphic was later than most in coming out with a CRT machine which had digital fonts. Was this an explicit effort not to cannibalize existing product lines? Did product development take longer than anticipated? In retrospect, what would you change?

The transition to front-end systems and software

Despite Compugraphic's original strength in "computerized typesetting," and some strong software-based products (e.g. the Unified Composer) , two acquisitions were made (Quadex and One Systems) to establish a stronger position in this market.

- Were these acquisitions considered central to establishing software development capabilities within Compugraphic? What efforts were made to develop capabilities in-house?

- What organizational changes were made to accommodate the shift from hardware to software-based systems? Was there a sudden surplus of hardware engineers (EEs and MEs), or was the transition slow enough that natural attrition allowed the firm to replace them with software engineers?

- What percentage of R&D resources were allocated to FES/software development as opposed to output device development? How were those decisions made? Were all components of MCS systems developed by the same group, or were output devices separate from FES/software?

General Issues

- How important was patent protection in enabling CG to appropriate the benefits of its R&D?

- One of Mergenthaler's strengths from both a product development and a marketing perspective was its international presence. At what point did international markets become a priority for Compugraphic? Did you ever consider establishing overseas product development groups?

- As CEO, what were your priorities in the 70's? How did those shift in the 80's?

- What other critical issues have I not touched on?

Photon

As the early innovator in phototypesetting, one might have expected Photon to establish a strong, sustainable position in the market. Instead, they struggled from day one, and never quite recovered. What factors contributed to their failure?

- Were their products overengineered for the market? Did they invest too much in R&D for the return? Did they ever develop a strong sales force? Were their manufacturing costs too high? Other factors?

Mergenthaler Linotype

Whereas two hot metal incumbents, Intertype and Monotype, lost a great deal of market share in the move from hot metal to phototypesetting and never quite recovered, Mergenthaler survived the transition and eventually even prospered. What factors contributed to its success?

- Did the "hot metal" mentality of Intertype and Monotype, evident in their first generation phototypesetters, hold them back? How did Mergenthaler overcome this mentality?

Other Competitors

- A number of firms attempted to enter the output portion of the typesetter industry in the late 60's / early 70's. The majority of these firms, however, exited the industry after only a few years (Hell's Digiset/RCA's Videocomp, Fairchild's PTS 2000, Graphex, Singer's Photomix 70, Star's Comp Star 150, Seaco, Sun Chemical's Sunsetter, Rockwell MGD's Metro-set, and Bobst's Eurocat). Many of these firms were large with what would appear to be ample resources to devote to the typesetter industry. Why, in your opinion, did so many fail to establish a position in the market? Are you familiar with the particular circumstances of any of the individual companies?

Thank you in advance for your assistance. I understand that I am asking you to remember things from 30-plus years ago, so I don't expect you'll recall precise numbers and dates, but your general impressions would still be helpful. I look forward to speaking with you.

Best regards,

Mary Tripsas

Appendix C:

New Entrants to the typesetter industry, by generation

Table C.1

New entrants in the analog phototypesetter generation

Firm	Entry Year	Exit Year	Background Products	Related Market	Related Technology
Photon	1956	1975	Lithomat, offset printing supplies	x	
American Type Foundry	1958	1970	Metal Type Foundry	x	
Alphatype	1961	entered next generation	Display lettering machine, Filmotype	x	x
Crossfield Electronics	1962	1972	Electronic Printers	x	x
Berthold	1967	entered next generation	Metal Type Foundry Display lettering machine	x	x
Fairchild Camera & Instrument	1967	1972	Electronic photoengraving, Teletypesetter Systems, Electronics, Semiconductors	x	x
Compugraphic	1968	entered next generation	Computerized typesetting tape processors	x	x
AM Varityper	1969	entered next generation	Justifying typewriters, offset duplicators,	x	
Singer (Friden)	1969	1975	Justifying typewriters Sewing machines Misc electronics	x	x
Graphex	1969	1970	Small web offset presses	x	
Star Parts	1970	1972	Linecaster supplies	x	
Graphic Systems	1970	1978	De Novo (Compugraphic spin-off)		
Bobst	1972	1981	Printers	x	
Dymo	1972	1979	Graphic arts labeling	x	
Dr. Boger	1975	entered next generation	Printers, Electronics	x	x
Itek	1976	entered next generation	Graphic image processing	x	x
Wang	1978	1982	Office systems		x

Table C.2

New entrants in the digital CRT phototypesetter generation

Firm	Entry Year	Exit Year	Description	Related Market	Related Technology
Hell	1965	entered next generation	Digital screening	x	x
Alphanumeric / Autologic	1965	entered next generation	User	x	
RCA	1967	1971	Computers		x
IBM	1967	1970	Computers		x
Seaco	1971	1971	Computers		x
Rockwell MGD (Miehle Goss Dexter)	1972	1979	Printing presses, bindery equipment Aerospace Electronics	x	x
Information International Inc.	1972	entered next generation	Computers		x
Sun Chemical	1973	1975	Printing Ink	x	
Guttinger	1979	1980	Computers Typesetting software	x	x
Scitex	1982	entered next generation	Textile screening Graphic arts scanners	x	x
High Technology Solutions	1983	entered next generation	De Novo		
Chelgraph	1986	1989	De Novo (Linotype-Paul spin-off)		
Alpha System Partners	1986	1989	Computers		x
Ferranti	1986	1987	Computers/ front end systems	x	x

Table C.3

New entrants in the laser imagesetter generation

Firm	Entry Year	Exit Year	Description	Related Market	Related Technology
Purup	1980	entered next generation	Danish business forms printer	x	
Isys	1982	1983	Computers		x
Sim-X	1982	1983	Computers (flight simulation software)		x
Camex	1983	1989	Electronic publishing systems with text and graphics	x	x
ECRM	1985	entered next generation	Digital Process Cameras	x	x
Bidco	1985	entered next generation	Supplier of typesetter components: CRT assemblies, electronic sub-systems	x	x
Xenotron	1985	1986	Electronic publishing systems with text and graphics	x	x
Optronics	1988	entered next generation	High resolution filmwriters and scanners for scientific communities		x

Table C.4

New entrants in the Postscript laser imagesetter generation

Firm	Entry Year	Description	Related Market	Related Technology
Birmy Graphics	1988	Printing service bureau	x	
Hyphen	1988	Monotype and Xenotron distributor	x	
Infocom	1989	De Novo		
Digital Technology	1989	Front end systems	x	x
IIN	1990	De Novo		
Graphic Publishing Systems	1990	De Novo		
Barco Graphics	1990	Bar coding systems	x	x