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UNRAVELING THE PROCESS OF CREATIVE DESTRUCTION: COMPLEMENTARY ASSETS AND INCUMBENT SURVIVAL IN THE TYPESETTER INDUSTRY

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When radical technological change transforms an industry established firms sometimes fail drastically and are displaced by new entrants, yet other times survive and prosper. Drawing upon an unusually rich data set that covers the technological and competitive history of the typesetter industry from 1886 to 1990, this paper uses a combination of quantitative and qualitative analysis to unravel this process of creative destruction. It argues that the ultimate commercial performance of incumbents vs. new entrants is driven by the balance and interaction of three factors: investment, technical capabilities, and appropriability through specialized complementary assets. In this industry, specialized complementary assets played a crucial role in buffering incumbents from the effects of competence destruction, and an analysis that examined investment or technical capabilities in isolation would have led to misleading results. This work thus highlights the importance of considering multiple perspectives when examining the competitive implications of technological change.

INTRODUCTION

Why do incumbent firms sometimes fail drastically in the face of radical technological change, yet other times survive and prosper? This paper explores this question by analyzing the technological and competitive history of the global typesetter industry for a period of over 100 years. Drawing upon an unusually rich data set that includes detailed firm- and product-level data for every firm in the history of the industry, it traces the nature of technological change, firm responses, and product market performance. From its inception in 1886 through 1990, the industry has undergone three waves of 'creative destruction' (Schumpeter, 1950) where competence-destroying, architectural technological change transformed the industry. Incumbents were displaced by new entrants, however, in only one of these three shifts. By exploring the dynamics of each of these shifts in depth, this paper helps to unravel this process of creative destruction.

Two contrasting perspectives on the process of creative destruction are present in the literature. The first, following in the tradition of Schumpeter's early work (Schumpeter, 1934), paints a picture of relatively fluid industries where new entrants innovate with technologically superior products and displace incumbent firms, only to have the cycle repeated. This continual failure of established firms in the face of radical innovation has been documented in a number of empirical studies (Cooper and Schendel, 1976; Majumdar, 1982; Tushman and Anderson, 1986; Henderson and Clark, 1990; Christensen, 1993). In contrast, other research has built on Schumpeter's later work (Schumpeter, 1950), focusing on the advantages that established firms have over new entrants. For example, Teece (1986) argues that when incumbents possess critical specialized

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complementary assets, new entrants unable to contract for those assets may be at a disadvantage, despite their potential technological superiority, and Chandler (1990) in an exhaustive examination of the development of industrial economies identifies substantial advantages that accompany the scale and scope of large firms.

This paper sheds light on these two perspectives by breaking out three crucial factors that, together, influence the ultimate commercial performance of incumbents and new entrants: (1) investment in developing the new technology; (2) technical capabilities; and (3) the ability to appropriate the benefits of technological innovation through specialized complementary assets. The balance and interaction among these three factors determine whether incumbents or new entrants are more successful in the face of competence-destroying technological change.

In dissecting the differential success of incumbents and new entrants across multiple waves of technological change in the typesetter industry, this paper examines each of these three factors and the interaction among them. It finds, first, that lack of investment was not responsible for incumbent failure. Consistent with both economic theories of investment behavior (Arrow, 1962; Gilbert and Newberry, 1982; Reinganum, 1983) and theories of resource allocation (Christensen and Bower, 1996), incumbents invested significant amounts in the development of each new generation of technology. However, while incumbents invested in developing new, competence-destroying technology, the technical performance of the products they developed in each new generation of technology proved to be significantly inferior to the performance of new entrant products. In line with previous research, organizational architectures, routines, and procedures fine-tuned to fit with the prior generation of technology appear to have handicapped incumbents (Majumdar, 1982; Tushman and Anderson, 1986; Henderson and Clark, 1990).

Although incumbent products were technologically inferior in all three competence-destroying generations of technology, incumbents were displaced by new entrants in only one of these three generations. Examining the effect of each technological shift on the value of the incumbents' specialized complementary assets helps to explain this disparity. When specialized complementary assets unavailable to new entrants retained their value despite a technological shift, incumbents maintained their market position in the new generation of technology. These assets appear to have buffered incumbents from the effects of competence destruction, enabling them to sustain a high level of commercial performance despite their technological disadvantage. This result highlights the importance of considering multiple perspectives when analyzing the competitive implications of technological change.

The paper begins with a brief literature review followed by a description of the data and of the research setting, the typesetter industry. Each of the major technological shifts in typesetters is then categorized in terms of its effect on investment incentives, technological competence, and specialized complementary assets. The next section uses descriptive data to contrast incumbents vs. new entrants in terms of investment behavior, technical capabilities, and the ability to appropriate the benefits of innovation through complementary assets. The final section uses quantitative analysis of product market share to further understand the intersection between competence destruction and complementary assets and their joint effect on commercial performance.

LITERATURE REVIEW

A large body of literature has analyzed the relationship between technological change and the competitive position of incumbents and new entrants. This section provides a brief synopsis of this work in order to frame our expectations regarding three related questions: (1) What factors drive the investment behavior of incumbents and new entrants? (2) Given competence-destroying technological change, how does the technical performance of incumbents compare to that of new entrants? and (3) What factors drive the ability of incumbents and new entrants to appropriate the benefits of innovation in the product market? While separate research addresses each of these questions, relatively little work has examined the intersection between them. This section first examines each question and then summarizes how, in combination, the balance and interaction between investment, technical capabilities, and appropriability drive the commercial performance of incumbents and new entrants.

Investment behavior

Much theoretical work in economics has examined the differing incentives of incumbents and new entrants to invest in innovative activity. Building on early work by Arrow (1962) this stream of research suggests that when innovation is radical, in the sense that it replaces rather than competes with the old technology (i.e., the monopolist's postinnovation price is less than the preinnovation cost), then incumbent monopolists have less incentive to invest in the new technology than new entrants. In contrast, when innovation is incremental (i.e., it competes with the existing technology) then incumbents have greater incentives than new entrants to invest (e.g., Gilbert and Newberry, 1982; Reinganum, 1983).

An alternative explanation for incumbent failure to invest in new technology is put forth by Christensen and Bower (1996), based on empirical data in the disk drive industry. They argue that established firms fail to invest in developing radically new technology as a result of firms' resource allocation mechanisms. Since resource allocation in established firms is guided by the needs of existing customers, when radically new technologies are 'disrupting' in that they target emerging markets instead of addressing the needs of existing customers, then established firms quite rationally focus their research efforts away from the new technology. As resource dependence (Pfeffer and Salancik, 1978) would predict, the purchasing power of existing customers influences the investment patterns of the established firms. Similarly, if new technology is 'sustaining' in that it meets the needs of the existing customer base, then incumbent firms should rationally invest in the technology.

Technical capabilities

Technological progress in an industry is generally characterized as passing through long periods of incremental innovation punctuated by periods of radical change (Abernathy and Utterback, 1978; Dosi, 1982; Sahal, 1985; Tushman and 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.

Different stages of this technology life cycle have major implications for the technical capabilities of incumbents and new entrants. During an incremental period, when technological innovation builds upon the capabilities of established firms, they have an advantage over new entrants. Established firms develop organizational structures, routines, and procedures that enable them to efficiently process information within the context of the existing technological regime (Burns and Stalker, 1961; Galbraith, 1973; Arrow, 1974; Nelson and Winter, 1982). When faced with a radical, competence-destroying technological shift, however, established firms are often at a disadvantage (Tushman and Anderson, 1986). Core competencies during a period of incremental innovation can become 'core rigidities', making it difficult for a firm to adapt (Leonard-Barton, 1992). Even if component technologies remain constant, architectural innovation—changes in the way components interface—can destroy the value of existing beliefs and patterns (Henderson and Clark, 1990). Finally, years of incremental innovation may result in selection-induced inertia, as only firms with stable structures and activities survive (Hannan and Freeman, 1977, 1984); such firms will find change difficult. As a result competence-destroying technological discontinuities often result in inferior technical performance on the part of established firms (Cooper and Schendel, 1976; Majumdar, 1982; Tushman and Anderson, 1986; Henderson and Clark, 1990; Afuah, 1994).

In contrast, Christensen and Bower (1996) found that in the disk drive industry established firms did not have difficulty developing new technology, even when innovation was architectural in nature. Despite the fact that innovation was radical in an organizational sense, incumbents had the resources and ability to develop new capabilities. This result is consistent with other empirical work that has demonstrated the strength of large research labs in coming up with new ideas (e.g., Freeman, 1982; Chandler, 1990). It is also possible that these incumbents possessed what Teece, Pisano, and Shuen (1997) call 'dynamic capability . . . the capacity of a firm to renew, augment, and adapt its core competencies over time'. Given these two conflicting perspectives, there is no clear prediction as to whether established firms will have inferior technological performance in competence-destroying technological generations.

Appropriability through complementary assets

When incumbents experience a technological disadvantage in the face of competence-destroying technological change, the extent to which that disadvantage translates into a commercial disadvantage may depend upon the other assets possessed by established firms. While in his early work Schumpeter (1934) argued that entrepreneurs should be responsible for most innovation, later work (Schumpeter, 1950) suggests that large established firms with capital and market power are in a stronger position to exploit innovation. Teece (1986) lays out a framework for identifying when the assets of large, established firms confer them with an advantage. He uses the label complementary assets to describe factors such as specialized manufacturing capability, access to distribution channels, service networks and complementary technologies. Teece distinguishes between generic, specialized, and cospecialized[1] complementary assets. Whereas generic assets have multiple applications and can be easily contracted for, specialized and cospecialized assets are useful only in the context of a given innovation. If a firm has proprietary access to the specialized complementary assets necessary for the commercial exploitation of an innovation, then that firm has a distinct advantage. Under a regime of weak intellectual property protection when an innovation can easily spill over to competing firms, complementary assets become particularly important if a firm is to appropriate the benefits of its innovation.

By explicitly considering the importance of complementary assets, one gains insight into the performance of incumbents and new entrants. As Teece (1986: 301) notes:

> Business commentators often remark that many small entrepreneurial firms which generate new, commercially valuable technology fail while large multinational firms, often with a less meritorious record with respect to innovation, survive and prosper. One set of reasons for this phenomenon is now clear. Large firms are more likely to possess the relevant specialized and cospecialized assets within their boundaries at the time of a new product introduction.

Empirical support for the value of specialized complementary assets is found in the medical diagnostic imaging industry. Mitchell (1989, 1992) finds that when competence-destroying innovations have low transilience (Abernathy and Clark, 1985) in that they do not substantially change the market/customer linkages, then incumbents perform well in the market. The sales/service relationships of the incumbents serve as a specialized complementary asset that new entrants find hard to contract for or imitate. The continued value of these assets can serve as a buffer when firms are faced with competence-destroying technological change, protecting the firm from innovative new entrants. In a similar vein, Rosenbloom and Christensen (1994: 657) introduce the term 'value network . . . the system of producers and markets serving the ultimate user of the products or services to which a given innovation contributes'. They argue that when technological innovation causes a shift in the value network, then established firms are at a disadvantage. In contrast, even when new technology is competence-destroying, if the value network does not change, then established firms are less likely to suffer at the hands of new entrants.

While the ongoing value of specialized complementary assets can provide incumbents a buffer, technological innovation can destroy the value of these assets. The shift from electromechanical to electronic calculators provides an example (Majumdar, 1982). While this shift was competence-destroying in a technological sense, it also destroyed the value of the specialized complementary assets accumulated by the incumbent firms. The sales force and service networks of electromechanical calculator firms—about 1500 individuals per firm—were vital to successful competition in the old regime. 'You don't have a chance in this business without this capability' stated a senior executive of one firm (Majumdar, 1982: 34). Since electronic calculators were more reliable, however, service was less essential, and office equipment dealers became a viable alternative form of distribution. The electronic calculators supplied by new entrants were distributed through these dealers, thereby circumventing the need for a sales and service network. Given this

[1] Teece distinguishes between cospecialized assets, where innovation and assets are mutually specialized, as opposed to specialized assets, where either the innovation or the asset is more dependent upon the other. Since this distinction is not crucial to this analysis, the term 'specialized' is used to refer to both specialized and cospecialized complementary assets.

change, new entrants were successful in displacing established industry players.

It is also possible that new entrants to an industry can possess relevant complementary assets. Previous studies have shown that diversifying entrants are likely to perform better when they enter related markets (Rumelt, 1982; Montgomery, 1985; Montgomery and Harihan, 1991). In fact, Chandler suggests that the majority of creative destruction is the result of this type of diversification:

> The major challengers in the capital-intensive industries of the twentieth century were not smaller firms that took advantage of changes in technologies and markets . . . far more often the successful challengers were long-established companies, usually first movers, from other countries or from other industries in the same country . . . Here the established enterprise became Schumpeter's entrepreneur. (1990: 601–602)

This leads one to expect that new entrants with relevant specialized complementary assets are more likely to be successful than those without them.

Synthesis

In summary, the previous discussion identifies three important elements driving incumbent vs. new entrant performance in the face of radical technological change: investment, technical capabilities, and appropriability through specialized complementary assets. This paper argues that the expected outcome in terms of ultimate commercial performance depends upon the balance and interaction among them. If incumbents choose not to invest in the new technology, then new entrants that make the investment will dominate the market for the new technology. If incumbents do invest, but their technological performance is inferior to that of new entrants, then, assuming a regime of weak intellectual property protection, their commercial performance will depend upon whether the technological shift also devalued the relevant specialized complementary assets necessary to appropriate the benefits of innovation. If incumbents possess these assets, and due to their specialized nature they cannot be acquired by new entrants, then incumbents are likely to dominate the market even if their products are technologically inferior. If, however, the technological shift also decreased the value of these complementary assets, then the incumbents have no buffer from competition and new entrants should dominate.

Finally, if incumbents invest in the competence-destroying technology and their technological performance is on par or superior to that of new entrants, the commercial result is still dependent upon who possesses the necessary specialized complementary assets. If the technological change does not devalue the incumbents' complementary assets, then they will clearly dominate in the market. If, however, incumbents' complementary assets are devalued and diversifying new entrants possess relevant specialized complementary assets, the new entrants can be expected to dominate, even if their technology is initially inferior. If neither incumbents nor new entrants already possess specialized complementary assets, then it is unclear which firms will dominate.

DATA AND RESEARCH SETTING

The data

These issues are examined through a study of the technological and competitive history of the typesetter industry for a period of over 100 years. The industry provides a particularly good setting in which to understand the effect of technological change on competition. Between 1886 and 1990, the industry experienced three waves of radical, competence-destroying technological change, accompanied by a great deal of variation in the competitive landscape. In total 42 different firms participated in the industry, with a maximum of 25 competitors and a minimum of three in the industry at any given point in time. Industry participants have also invested substantial amounts in R&D, with industry R&D/sales averaging 10 per cent from 1985 to 1990.

The core of the data consists of a comprehensive longitudinal data set covering the entire history of the worldwide typesetter industry from the inception of the industry in 1886 through 1990. It was collected during a 14-month field-based study conducted from the fall of 1993 through the winter of 1995. The data set includes the entry date of every firm in the industry and, for those firms that exited, the exit date. Detailed data for 95 per cent of the products introduced by these firms covers product performance characteristics, price, and unit sales over time. Unfortunately quantitative R&D investment data were unavailable for the majority of firms. Firm-level data are supplemented by aggregate industry-level data, including industry size and growth.

Quantitative data were supplemented with qualitative data about how organizations responded to new technology, including in-depth case studies of multiple firms. Detailed schematics of typesetter machines from each generation of technology were reviewed with development engineers in order to understand changes in machine components and architecture. This work enabled a careful determination of the nature of technological change and its effects on organizational competence.

These data come from a combination of primary and secondary sources including company and trade association archives, field interviews, personal records of retired employees, industry consultants, industry historians, government records, as well as industry trade and scientific journals. In total, over 50 interviews were conducted, with interviews lasting from 2 hours to all day. Wherever possible, data have been cross-checked with multiple sources.

The typesetter industry

Typesetting is the process of arranging text as input to the printing process. While this process was accomplished manually for many years based on the invention of moveable type by Johann Gutenberg in about 1440, the invention of the Linotype machine by Ottmar Mergenthaler in 1886 sparked the beginning of the typesetter industry. A typesetter machine generally performs three functions: text input, text formatting, and text output. Text is input by an operator from a prepared manuscript, usually via a typewriter-like keyboard. The text is then formatted either by the operator or automatically. The output of the typesetter, either paper or film, is then used to create a printing plate. This plate is used on a printing press to produce high-volume output. Customers for typesetter machines include newspapers, commercial printers, high-end typographers and corporate 'in-house' publishers.

TECHNOLOGICAL CHANGE IN THE TYPESETTER INDUSTRY

From the discussion above, three effects of technological change are key in understanding how it will drive competition: the effect on (1) investment incentives, (2) technological competence, and (3) specialized complementary assets. In this section each new generation of typesetter technology is categorized in terms of its effect on each of these factors. There have been three generations of radical technological change since the initial invention of mechanical, 'hot metal' typesetter technology in 1886: analog phototypesetting (1949), digital CRT phototypesetting (1965), and laser imagesetting (1976). Each generation of technology is described in the Appendix.

The effect of each generation on investment incentives

Each of these generations was incremental in the economic sense in that the old generation of technology continued to compete with the new generation. This competition is evident in Figure 1, which charts industry sales by generation of technology over time. Even though the first analog phototypesetter was introduced in 1949, it was not until 1968 that half of annual industry sales were comprised of phototypesetters. Similarly, there was a 19-year lag between the introduction of CRT machines in 1965 and their dominance in 1984, and a 12-year lag between the introduction of laser imagesetters in 1976 and their dominance in 1988.

Evidence of the competition among generations of technology is also evident in the trade press and in government publications, with numerous articles comparing the old and new technologies in order to identify the conditions under which a potential customer should purchase one or the other (e.g., U.S. Congress Joint Committee on Printing, 1970; National Composition Association, 1973). Entrants with each new technology were therefore not able to monopoly price, ignoring competition from the old technology. The price/performance of each new technology did improve over time, however, resulting in eventual substitution for the old technology.

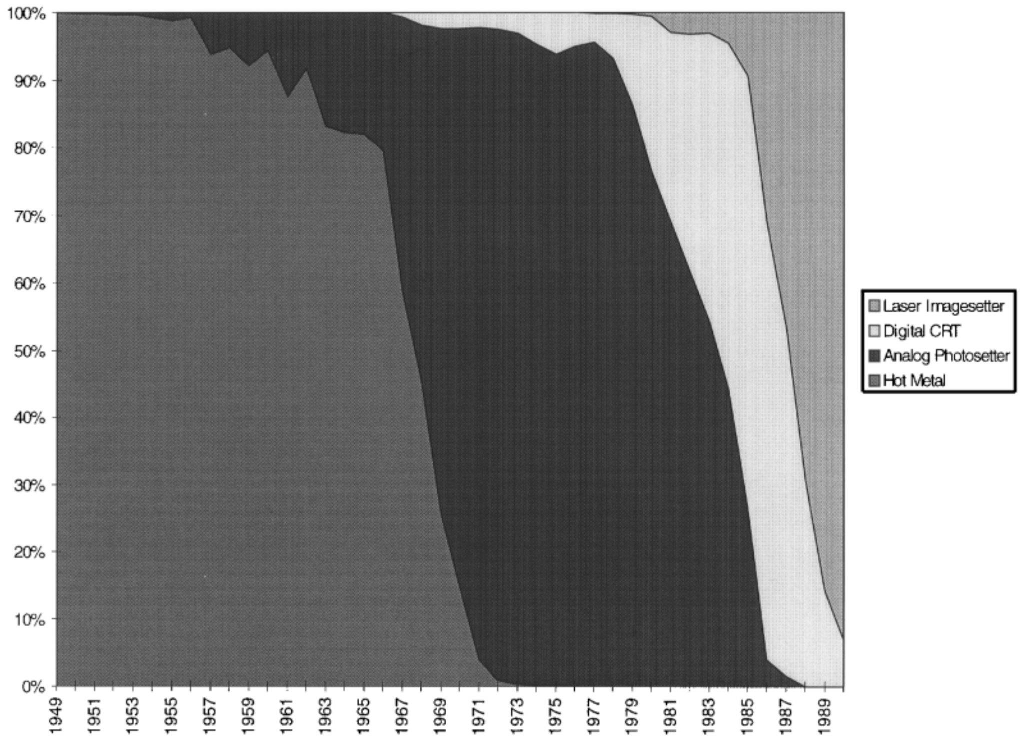

Figure 1. Percentage of typesetter sales by technology, 1949–90

The effect of each generation on technological competence

Two measures were used to gauge how each generation of technology affected the value of the technological competence of established firms. First, changes in the required skills for a product development team were compared for each generation. This measure, however, fails to capture any sense of architectural change in the product. Product components, interfaces, and overall machine logic were therefore also compared in order to gain a better understanding of architectural change.

Changes in development team skill base

The analysis of the skills required to develop a product in each generation of technology was based on an examination of the staffing of a subset of development projects. The goal was to compare the skills of individuals on development teams for each generation of technology in order to gauge how radical a new generation was in terms of new skills required. A number called 'new skills' was computed for each generation of technology (see Table 1) as follows.

For each project team in the sample (5 hot metal; 4 analog phototypesetters; 4 digital CRT phototypesetters; and 3 laser imagesetters), relevant skills of team members were identified. Then, the percentage of the development team with each skill was calculated.[2] These percentages were averaged across projects within a given generation. The average for each generation was then compared to the previous generation to determine the percentage of skills that were new. For instance, the entire development team for a hot metal machine was comprised of mechanical

[2] In the majority of cases archival project staffing records were used to determine development team skills. Where staffing records were unavailable, development engineers were asked for their best recollection of the composition of development teams. Engineers' recollections of research projects going back to the 1950s suffer two potential problems: a lack of memory and potential bias, given the knowledge of the subsequent turbulence resulting from new technology. Interviewees were surprisingly good, however, at recalling the names and backgrounds of team members. To address the potential bias that might accompany a recollection, at least two members of each development team were interviewed.

Table 1. The effect of typesetter technological innovation on development team skills

Generation	Hot metal	Analog phototypesetter	Digital CRT phototypesetter	Laser imagesetter
Development team skills	Mechanical engineer	Lens designer	Lens designer	Lens designer
		Mechanical engineer	Optomechanical engineer CRTs	Optomechanical engineer Lasers
		Optical engineer		
		Electrical engineer Electromechanical	Electrical engineer Solid state CRTs Minicomputers	Electrical engineer Solid state Lasers Microprocessors Raster image processing
			Software Applications	Software Applications Raster image processing Font encoding
Skill loss	n/a	90%	70%	50%
Competence-destroying?	n/a	Yes	Yes	Yes

engineers. In the analog phototypesetter generation, however, on average only 10 per cent of the team were mechanical engineers—the other 90 per cent of the skills of team members were new. The value of 'new skills' for the analog phototypesetter generation was therefore 90 per cent.

While detailed information about development team staffing was available for only a subset of project teams, I believe these projects are representative in that they include multiple firms and span multiple years. There was also a high degree of consistency across projects within a generation in terms of the mix and balance of skills. The mix of skills was the same for all projects within each generation, and no given skill category varied by more than ± 10 per cent across the projects within a generation.

If a large percentage of the required skills in a generation were new, then the relative value of an incumbent's existing skill base decreased. A generation was classified as competence-destroying from the standpoint of skill base if 50 per cent or more of the skills in a generation were new. With new skill requirements of 90 per cent, 70 per cent, and 50 per cent, the second, third, and fourth generations of typesetter technology were all competence-destroying.

Architectural changes

A simple comparison of skills fails to capture any changes in the architecture of the machines from different generations, so this analysis was supplemented by an examination of the characteristics of the overall product architecture relative to the preceding generation. All three generations were also competence-destroying from the standpoint of their effect on architectural knowledge.

Table 2 compares the controlling machine logic, the method of character escapement (spacing of characters), the method of font storage, and the method of character output for each generation. For each of these technological shifts, both product components and interfaces changed. For instance the font output component changed from pouring molten lead, to exposing a photograph of a character with xenon flash, to writing a character digitally with a CRT, to writing a character digitally with a laser. In addition, the final laser generation enabled the output of both text and images, thus requiring a shift to raster

Table 2. The effect of typesetter technological innovation on architectural knowledge

Generation	Controlling machine logic	Escapement (character spacing)	Font format	Character output	Effect on architectural knowledge
Hot metal	Mechanical	Mechanical	Metal matrix	Hot metal	n/a
Analog phototypesetter	Electromechanical	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; microprocessor	Electronic	Proprietary digital outline	Laser raster strokes	Destroy

image processing where horizontal strokes were written onto a page. The manner in which component interfaces were managed—i.e., the machine logic—moved from mechanical to electromechanical to electronic to primarily software.

The effect of each generation on specialized complementary assets

Extensive discussions with industry participants identified three salient complementary assets in the typesetter industry: specialized manufacturing capability, a sales and service network, and a font library. The overall effect of each new generation of typesetter technology on the value of incumbents' specialized complementary assets was therefore based on an examination of these three factors. In different industries other specialized complementary assets such as access to distribution channels or exclusive supplier relationships have value. In this industry, however, a direct sales force remained the preferred method of distribution throughout the period under consideration, so access to distribution channels was therefore not relevant. Similarly, exclusive supplier relationships did not play a role in the industry. Table 3 summarizes how each technological generation affected the value of specialized complementary assets relative to their value in the prior generation.

Specialized manufacturing capability

Three firms—Mergenthaler Linotype, Intertype, and Monotype—dominated the original hot metal typesetter era, controlling 99 per cent of the market by 1916. Each of these firms developed very strong specialized manufacturing capabilities and made ongoing investments in continuous improvement. For instance, a 1940 company monograph entitled 'The Autobiography of Capital B' describes the manufacturing of hot metal matrices at the industry leader, Mergenthaler Linotype:

> In the matrix department are 154 machine tools which are necessary for the many operations in the production of Linotype matrices . . . During the last 30 years . . . 90% of the machines and attachments have been redesigned and specially built in our own tool room. (Linotype & Machinery, Ltd., 1940)

The shift to analog phototypesetting destroyed the value of this manufacturing capability. While production of hot metal machines and matrices required highly specialized machine tooling and sophisticated metal shops, phototypesetter production required much less specialized equipment. Electronic components used were similar to those used in other electronic products, and some manufacturing was outsourced. In Teece's (1986) terms, manufacturing capability became a 'generic' complementary asset that could be easily contracted for. It remained a generic complementary asset in the CRT and laser generations.

Sales and service network

A strong sales and service network was a crucial specialized complementary asset developed by hot metal manufacturers given the critical nature of typesetting to buyers. The primary typesetter

Table 3. The effect of typesetter technological innovation on the value of specialized complementary assets

Generation	Specialized manufacturing capacity	Sales and service network	Extensive proprietary font library	Devalue specialized complementary assets?
Hot metal	High value	High value	High value	n/a
Analog phototypesetter	Much lower value than prior generation	Much lower value than prior generation	Same value as prior generation	Yes
Digital CRT phototypesetter	Same value as prior generation	Same value as prior generation	Same value as prior generation	No
Laser imagesetter	Same value as prior generation	Same value as prior generation	Same value as prior generation	No

buyer segments during this era comprised newspapers/magazines, commercial printers, and typographers/advertisers. The typesetter was necessary for each of these segments to do business. Newspapers, for instance, had deadlines to meet, and typesetting was on the critical path for getting the paper to press. Typographers, whose primary task was to translate manuscripts into typeset output, could not carry on their business without a typesetter machine. Commercial printers needed typeset material to print. So in addition to technical purchase criteria (e.g., speed, flexibility, and output quality), reliability and service were also important purchase criteria for each of these segments (see Table 4). In response to these customer needs, all three hot metal incumbents established strong international sales and service networks. Mergenthaler Linotype and Monotype in particular had a strong presence in Third World countries.

The value of the established firms' sales and service networks decreased with the advent of analog phototypesetters due to the emergence of a new buyer segment, the in-house publisher. Corporations with a critical mass of in-house publications now found it worthwhile to bring the typesetting of those publications in-house as opposed to contracting out for the service. Previously the noise levels and safety hazards of molten lead had precluded the operation of typesetter machines in an office environment. Analog phototypesetters eliminated these problems. Since established players had no sales presence in this new segment, they were on an equal footing with new entrants, and perhaps even at a disadvantage relative to diversifying entrants with ties to these customers.

Although this new buyer segment diminished the value of the existing sales/service network, it did not result in a completely new set of buyer purchase criteria in the manner that Christensen and Bower (1996) found with new generations of disk drives. While these new buyers cared more about noise and safety, these were typically minimum criteria. Purchase decisions were still based on more traditional criteria such as technical performance (speed, flexibility, output quality) and reliability/service (see Table 4). In addition, the new segment was still served by a sales force, not alternate distribution channels.

While the second generation of technology resulted in a new market segment, the third and fourth generations—CRT and laser machines—did not. The same set of buyers (now including in-house publishers) continued to be served through the same set of salespeople. As a result, the sales and service networks built up during the second generation remained valuable specialized complementary assets during the third and fourth generations.

Proprietary font library

The size of a manufacturer's font library affected the value of the firm's typesetter machine in much the same way the variety of software available for a computer affects its value to a buyer—a larger variety of available fonts made the typesetter more valuable. For three customer segments—typographers/advertisers, commercial printers, and in-house publishers—customer interviews indicated that the size of the available font library was one of the most critical purchase criteria (see Table 4). In order to compete in these segments,

Table 4. Overview of serving different typesetter market segments

	Newspapers	Typographers/ advertisers	Commercial printers	In-house publishers
Mode of distribution	Direct sales force	Direct sales force	Direct sales force	Direct sales force
Rank-ordered purchase criteria				• Noise level[a] • Safety[a]
	• Speed • Reliability • Service • Compatibility • Flexibility • Font library • Output quality	• Output quality • Font library • Reliability • Service • Flexibility • Speed • Compatibility	• Speed • Font library • Flexibility • Output quality • Reliability • Service • Compatibility	• Speed • Font library • Flexibility • Output quality • Reliability • Service • Compatibility

[a] Minimum purchase criteria.

customers indicated that a firm needed at least 500 typefaces, and even then was still at a disadvantage relative to firms that had larger selections. While newspapers required a smaller variety of fonts, they were often tied to a manufacturer that had proprietary ownership of a specific font that was important to the 'look and feel' of the paper.

Recognizing the importance of fonts, each of the hot metal incumbents invested heavily in developing proprietary font libraries. As early as 1895 the leading firm's annual report (Mergenthaler Linotype) stressed the need to invest in typeface development, with expenditures for the design of new fonts exceeding the amount spent on R&D. In 1902 Mergenthaler had a library of over 100 typefaces. By 1913 the library had grown to 1000 typefaces, and by 1923 it had reached 2000. This library included not only various roman alphabet fonts but also a number of foreign language fonts such as Greek and Cyrillic. Despite large investments, it took Mergenthaler about a year to develop 100 typefaces. At that rate, it would take an entrant 20+ years to duplicate Mergenthaler's library as it stood in 1923, and 5 years to reach the minimum competitive level of 500 fonts identified by customers.

A proprietary font library retained its value throughout the three subsequent generations of technology. While established players had to transfer typeface designs between formats, 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 entrants did simply attempt to copy typefaces, this process was much more difficult than originally anticipated. For instance, despite investing significant amounts in font development, it took Compugraphic, the most successful second-generation new entrant, 10 years and approximately $23.8 million 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 trademark.[3] Customers preferred the true 'Helvetica' to some 'cheap imitation'.

In addition, if an established customer needed 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

[3] Many of today's well-known typefaces, such as Helvetica, were trademarked by Mergenthaler during the early hot metal era. Once it became clear in a 1970 court decision that fonts could not be patented or copyrighted, these trademarks became critical for intellectual property protection of fonts.

> 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)

In summary, all three new generations of technology in the typesetter industry should have created an incentive for incumbents to invest. They were all incremental from an economic standpoint, and 'sustaining' from a resource allocation perspective in that they appealed to existing customers. All three generations were competence-destroying, making the technological skills and routines of incumbents obsolete. Of these three competence-destroying technological generations, however, only the second—analog phototypesetters—also decreased the value of specialized complementary assets. Two of the three specialized complementary assets examined lost their value in the shift to the second generation. So, while one asset—a font library—did retain value, the overall value of specialized complementary assets decreased significantly in the second generation.

How then, did the process of creative destruction unfold as each generation of new technology substituted for the old? The next three sections examine each of the three links in the process described earlier. Did new entrants and incumbents invest in the new technology? Given that they invested, how did the technical performance of incumbent machines compare to that of new entrants? Did the ongoing value of specialized complementary assets buffer incumbents from the effects of inferior technical performance, and did possession of relevant specialized complementary assets facilitate the entry of diversifying firms?

CREATIVE DESTRUCTION IN THE TYPESETTER INDUSTRY

Investment behavior of new entrants and incumbents

As both the economic and innovation literature would predict, there was very little investment by new entrants in hot metal typesetter technology during the many years of incremental hot metal innovation. Introduced in 1886, Ottmar Mergenthaler's Linotype architecture became dominant by 1903, with over 50 per cent of annual industry sales. Other than four new entrants (only one of which survived) around 1911 when key patents expired, there was no entry into hot metal typesetting between 1903 and 1970, when production of hot metal machines in the United States ceased.

Entrants did, however, clearly perceive and pursue opportunities created by the three subsequent generations of competence-destroying technology. There were 17, 14, and 8 new entrants in the second, third, and fourth generations of technology. As Chandler (1990) would predict, these entrants were overwhelmingly diversifying firms with related experience. In particular, for the analog phototypesetter generation of technology, 88 per cent of new entrants had prior related market knowledge, having sold other graphic arts products to typesetter buyers. This number was 50 per cent for the CRT generation and 62 per cent for the laser generation.

Since each new typesetter generation was incremental from an economic standpoint and 'sustaining' from a resource allocation standpoint, one would expect to find incumbent investment greater than new entrant investment. Unfortunately, a lack of data precludes a comparison of the levels of incumbent and new entrant investment. All that can be tested is whether and when the incumbents invested.

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. All three first-generation hot metal firms invested in developing the second generation of technology. Of 11 incumbents in the second generation, 10 invested in the third, and of 11 incumbents in the third generation, 9 invested in the fourth. In addition, qualitative data from interviews with both management and development engineers indicate that the level of investment by incumbents was at least equivalent to that of new entrants.

Moreover, incumbents invested in second-generation machines much earlier than new entrants. The average year that hot metal incumbents announced their initial second-generation machine was 1955 as opposed to 1967 for new entrants. Incumbents and new entrants did not differ significantly in their investment timing for the third and fourth generations. For the third generation, the mean introduction date for incumbents was 1975 as opposed to 1973 for new entrants, and in the fourth generation incumbents' mean introduction date was 1983 vs. 1984 for new entrants.

Technical performance of incumbents vs. new entrants

This section begins by looking in depth at two examples of incumbent development efforts in order to understand the degree to which incumbents were handicapped by their prior experience. It focuses on the development of second-generation analog phototypesetters by hot metal incumbents Intertype and Monotype. 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 and, as a result, had significantly inferior performance.

Intertype

Intertype began work on a phototypesetter in 1936 after the firm's president was approached about the idea during a European business trip. He assigned the development task to the hot metal chief engineer. This individual 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 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 and was installed at the U.S. Government Printing Office in Washington in 1946. The machine was essentially a modified hot metal typesetter and did not operate any faster than its hot metal counterpart. The basic architecture was identical except that the mechanically circulating matrices were modified to have a film image of a character embedded in them as opposed to a mold of a character. The component of the machine where hot metal used to be injected into the matrix was replaced by a camera that photographed one character at a time. The film carriage advanced mechanically between letters, based on the width of the matrix.

This awkward machine, called the Fotosetter, shipped in 1949 and was the first commercial phototypesetter on the market. 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. The 'success' of the Fotosetter led to additional incremental phototypesetter innovation within the old hot metal architecture. The Intertype 1956 Annual Report (p. 4) 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'. In the meantime, new entrants announced truly innovative electromechanical machines that incorporated significantly improved technology, and by 1961 Intertype's share of the phototypesetter market had fallen from 100 per cent to only 12 per cent.

Monotype

Monotype also became involved in photocomposition at an early stage. The manager of the firm's London office commenced research on a phototypesetter in the early 1930s although without the official sanctioning of the corporation. His design utilized many of the concepts embodied in the hot metal Monotype machine. Patents on the machine, called the Rotofoto, date from 1936.

Shortly after World War II Monotype formally initiated a project to develop a commercial phototypesetter. 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 both the Rotofoto and the Monotype hot metal machine. Rather than cast metal into a mold, a selected character was positioned over a flash and exposed onto film. It ran at the same speed as a hot metal Monotype, and only one size could be set at a time. The machine was not installed commercially until 1957, and by 1959 only 5–10 machines had been placed.

In the mid-1960s while new entrants were developing electromechanical machines, Monotype was continuing to make incremental improvements to the mechanical Monophoto. One Monotype employee at the time made an attempt to increase the firm's interest in electronics 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 electromechanical machine—the Monophoto 400—in 1969, it was described by one industry expert as 'an odd amalgam of mechanics, fluidics and electronics . . . with anachronistic technical concepts which ran counter to prevailing development trends' (Wallis, 1993: 4).

Overall technical performance of incumbents vs. new entrants

Intertype and Monotype were clearly handicapped by their many years of experience in hot metal technology when they attempted to develop second-generation machines. This section examines whether their experience was representative of incumbent firms in general by comparing the average technical performance of incumbent and new entrant machines for each generation of technology. As a measure of technical performance product speed is used. While many criteria are important to typesetter buyers, speed is the one criterion valued highly by all segments (see Table 4), and in interviews with product development engineers it was consistently identified as a primary goal. 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 5 compares the average speed of machines made by incumbents as opposed to new entrants for each competence-destroying generation. A comparison of the average speed of the first machine introduced by each incumbent with the average speed of the first machine of each new entrant indicates that in all three generations incumbents' machines were significantly slower. However, as discussed earlier, incumbents invested in the second generation of technology much earlier than new entrants did. An additional comparison was therefore performed for the analog phototypesetter generation in which incumbents' second machines (average introduction date of 1963) were compared to the first machines of new entrants (average introduction date of 1967). The average speed of the incumbent second machines, 19 newspaper lines per minute, was still much slower than the new entrants' average speed of 41, but no longer significantly so in a statistical sense. Since there were only three incumbents for this generation, however, there is little statistical power, and this result is not surprising.

Finally, a comparison of all machines introduced after the first machine was made in order to determine whether incumbents eventually caught up technologically with new entrants. Data for this analysis were only available for the analog phototypesetter and digital CRT generations. For analog phototypesetters, although the absolute difference between average speeds—26 newspaper lines per minute vs. 55—seems substantial, it is not statistically significant. Once more, the small sample size may be limiting the power of the test. In the case of digital CRT machines, a statistically significant difference between the average speed of incumbent and new entrant machines remains. This analysis provides limited evidence that, even after several years of experience in the new technology, incumbents did not catch up technologically with new entrants. The effect of prior routines and procedures appears to have been quite persistent.

Appropriability and specialized complementary assets

As discussed earlier, when an incumbent's technological competence is destroyed but the incumbent still controls valuable specialized complementary assets, it should be able to protect its competitive position despite developing new technological capability more slowly than new entrants. Similarly, new entrants that possess relevant specialized complementary assets should have an advantage over those that do not. This section examines these expectations in the context of the three competence-destroying generations of technology.

Descriptive data

The descriptive data clearly support the buffering of incumbents by specialized complementary assets that retain their value. Table 6 summarizes the effect of each generation on investment, technical capabilities, and complementary assets and

Table 5. Technical performance of incumbent and new entrant machines: Average speed (newspaper lines per minute) of machines, all incumbents vs. all new entrants (pairwise two-tailed *t*-test)

Technological generation	Incumbent machines	New entrant machines	Significance
Analog phototypesetters			
First machine	14	41	$p < 0.10$
Incumbent second machine vs. new entrant first machine	19	41	n.s.
All subsequent machines	26	55	n.s.
Digital CRT phototypesetters			
First machine	399	974	$p < 0.05$
All subsequent machines	547	1583	$p < 0.05$
Laser imagesetters			
First machine	381	648	$p < 0.10$

Table 6. Summary of descriptive data on incumbent vs. new entrant performance

Generation	Incumbent incentive to invest?/Did incumbents invest?	Technological competence destroyed?/Incumbent technical performance inferior?	Specialized complementary assets devalued?	Number of new entrants	Market share of new entrants
Analog phototypesetter	Yes/Yes	Yes/Yes	Yes	17	89%
Digital CRT phototypesetter	Yes/Yes	Yes/Yes	No	14	16%
Laser imagesetter	Yes/Yes	Yes/Yes	No	8	12%

then lists the number of new entrants in each generation and how successful they were. In the case of the two generations where specialized complementary assets retained their value, there were a large number of new entrants, 14 in the CRT and eight in the laser generation, but new entrants captured only 16 per cent and 12 per cent respectively of cumulative CRT and laser unit sales. New entrants perceived an opportunity due to the changing technology, but the ownership of specialized complementary assets by incumbents, a sales/service network and font libraries in particular, appear to have protected the incumbents from competition. In contrast, new entrants to the analog phototypesetter generation, where both technological competence and specialized complementary assets were devalued, captured 89 per cent of the cumulative market. Although font libraries did retain value in this generation, other important complementary assets—specialized manufacturing capability and sales/service networks—lost value, and the combined effect of these factors was stronger than the protection provided by a font library.

Given that incumbents to the analog phototypesetter generation lacked some of the relevant specialized complementary assets, one would expect that diversifying new entrants that possessed them would perform well. The next section examines one such entrant, AM Varityper.

The case of new entrant Varityper

As discussed earlier, the second generation of technology—analog phototypesetters—created a new market segment: in-house publishers. AM Varityper, a subsidiary of diversified conglomerate AM (Addressograph-Multigraph), was ideally positioned to take advantage of this emerging segment given its prior relationships with corporate buyers interested in graphic arts products. The firm captured 28 per cent of the cumulative unit share of the analog phototypesetter generation.

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.[4] 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 to upgrade and produce higher-quality internal publications. Phototypesetters were generally 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 also lacked a sales presence in that segment of the market. Varityper had both a good reputation and a strong sales and service presence. Varityper also had a moderate font library since it offered a variety of fonts for use in its justifying typewriters. In addition, the firm 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, so management contracted with the technological leader in the industry: a new entrant, Photon. AM Varityper's first machine, shipped in 1969, was designed and manufactured by Photon. Given the strength of Varityper's sales organization the machine did moderately well, and three more models were announced in 1970 and 1971 with similar results. At the same time, the firm was gradually developing its own technological expertise. Announced in 1972, the first internally developed product was a low-cost version of the Photon machine. While only moderately successful, the effort gave the development organization crucial 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 machine with a full-size video screen for text input and editing.[5] It was also relatively low cost and targeted at the in-house segment where AM Varityper was strong. Over 11,000 Comp/Sets were sold over the life of the product, compared to only 3500 units sold for the most successful incumbent machine in this generation.

THE ROLE OF SPECIALIZED COMPLEMENTARY ASSETS

The prior section provided descriptive data in support of the importance of specialized complementary assets. When new technology was competence-destroying, but the value of incumbent specialized complementary assets was preserved (the CRT and laser generations), then incumbents maintained a strong market presence. In contrast, when complementary assets did not retain their value (analog phototypesetters), new entrants dominated the market. New entrants with relevant specialized complementary assets would be expected to perform well, and qualitative data about one such successful entrant were discussed. This section explores the degree to which quantitative analysis is consistent with these results.

Given a lack of available data on profits, product market share in the relevant generation of technology is used as a measure of commercial performance. The model controls for the amount of competition in the technological segment,

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

[5] Interestingly, the lead engineer on the Comp/Set 500 was a mechanical engineer who had previously worked on the design of justifying typewriters. When the focus of the organization shifted to electronics and optomechanical 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.

growth of the segment, and whether a product is a firm's first in the generation, and then uses dummy variables to measure the effect of incumbency and of complementary assets on performance. Of course, this model necessarily omits a variety of factors that might have also shaped market share, such as advertising levels or the size of the sales force. Unfortunately, data limitations preclude their inclusion.

Dollar market share is used as the dependent variable. This measure incorporates the two sources of advantage associated with new product introduction: an increase in realized demand and the ability to charge high prices. Since I am not interested in understanding the relation between these two factors *per se*, but in their combined effect, dollar market share is an appropriate measure. To carefully distinguish the relation between these two factors, one would need to estimate a differentiated product demand model (e.g., Trajtenberg, 1990; Bresnehan, Stern and Trajtenberg, 1996), and limitations on the data set preclude this.[6]

The incumbent dummy variable in the model is designed to capture the effect of differences between the technical performance of incumbent and new entrant machines since product performance is not explicitly included in the model. Given that all products in the sample come from competence-destroying generations of technology, one would initially expect incumbency to have a negative effect on commercial performance. Controlling for the effect of specialized complementary assets, however, a negative coefficient is expected only when both competence is destroyed and specialized complementary assets lose value. When complementary assets retain their value, they should buffer incumbents from the effects of competence destruction. One would also expect that new entrants with relevant complementary assets would perform better than new entrants without them. The expected coefficient of the dummy for new entrants with complementary assets is therefore positive.

The basic model is as follows (note the omitted dummy is for New Entrants that do not possess complementary assets):

$$\begin{aligned} Ln\ (Market\ Share_{it}) = {} & \alpha + \beta_1\ Competition_t \\ & + \beta_2\ Segment\ Growth_t \\ & + \beta_3\ First\ Product_{it} \\ & + \beta_4\ Incumbent_{it} * Complementary\ Assets\ Devalued_{it} \\ & + \beta_5\ Incumbent_{it} * Complementary\ Assets\ Not\ Devalued_{it} \\ & + \beta_6 New\ Entrant_{it} * Possess\ Complementary\ Assets_{it} \\ & + \epsilon_{it} \end{aligned}$$

An additional model that substitutes years of experience in the prior generation for the incumbent dummy variable is also tested in order to determine the effect of the length of incumbency. Variable definitions follow. Definitions and descriptive statistics are summarized in Tables 7 and 8.

Measures

The dependent variable: Dollar Market Share

In order to capture the initial effect of a product in the marketplace, dollar market share is measured for the first 3 full years of a product's life. Each product which lasts 3 years therefore has three observations. Products withdrawn after 1 or 2 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.

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.

[6] A more limited model that uses unit share as the dependent variable and relative price as an additional explanatory variable was examined. Since relative price is endogenous in that it is correlated with unobserved quality in the error term, two-stage least-squares techniques were used. Unfortunately, good instruments for relative price, such as cost data, were not available, so lagged relative price was used. The results of this model were qualitatively identical to the results obtained using dollar market share.

Table 7. Product market share model: Variables and measures

Variable	Measure
Market Share	The dollar market share of a product in a given year and generation of technology
Measures of technical experience	
Incumbent	Dummy variable set equal to one if a firm was present in the prior generation
Stock of Prior Experience	The number of years of experience a firm has in the prior generation of technology
Measures of specialized complementary assets	
Complementary Assets Devalued	Dummy variable set equal to one if this generation resulted in the devaluation of specialized complementary assets that had value in the prior generation (see Table 3)
Possess Complementary Assets	Dummy variable set equal to one if a typesetter new entrant had prior experience selling other graphic arts products to typesetter buyers
Controls	
Number of Competing Products	The total number of products competing in the generation at the beginning of the period
Segment Growth	Average unit growth for the prior 3 years for the given generation
First Product	Dummy variable set equal to one if this is the first product in the current generation developed by this manufacturer

Table 8. Market share model descriptive statistics

	Mean	S.D.	Minimum	Maximum
Market Share	15.0	18.0	0.06	78.8
Number of Competing Products	10.1	3.3	3	16
Segment Growth	0.53	0.46	–0.07	1.97
First Product	0.47	0.50	0	1
Incumbent	0.51	0.50	0	1
Stock of Prior Experience	18.2	28.0	0	85
Complementary Assets Devalued	0.50	0.50	0	1

Growth

Growth each year is measured as the average unit growth in a technological generation for the prior 3 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.

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 its 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.

Prior experience

An incumbent's prior experience is measured as 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. This measure is simply a richer way of capturing the potential liability of incumbent experience, and the expected effects on performance are the same as for the incumbent dummy variable.

Complementary assets devalued

If a product is in a technological generation that destroyed the value of specialized complementary assets relative to the prior generation (i.e., the analog phototypesetter generation), then this dummy is coded as one. The construction is based upon an in-depth examination of the industry and the technologies as discussed above.

Possess complementary assets

Dummy variable for diversifying new entrants set equal to one if they had related market experience, specifically prior experience selling graphic arts products to potential typesetter buyers. In an ideal case, one would have a scalar estimate of market relatedness, based on a number of factors including, for instance, whether the purchase decision maker was the same for the new market. Unfortunately, this level of detailed data was not available.

Results of modeling market share

Controls

The results of the analysis of market share are displayed in Table 9. The coefficient of the control variable *Number of Competing Products* is in the expected direction and the variable is highly significant. For each additional competing product in the market, there is about a 0.33 per cent decrease in market share. The *Growth* control variable, however, is not significant in any specification. Apparently faster growth did not enable new products to gain substantially more market share than products entering slower growth environments. The final control variable, *First Product*, was significant with a negative coefficient in all but one specification. A firm's first product in a given generation did not perform as well as subsequent products. Using the coefficients from specifications 2 and 3, being the first product in a generation resulted in a 0.56 per cent decrease in market share. 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.

The effect of specialized complementary assets

This section examines whether specialized complementary assets are in fact buffering incumbents from the effect of inferior technological performance. Specification 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 not significant. If one went no further, one might assume incumbents were not generally disadvantaged by competence destruction. In specification 2, however, when the interaction between *Incumbent* and the dummy variable *Complementary Assets Devalued* is included, the results change dramatically. When specialized complementary assets are devalued in addition to competence being destroyed, the effect of being an incumbent is significant and negative. Being an incumbent (vs. a new entrant) decreases market share by 1.01 per cent. When specialized complementary assets retain their value, however, the effect of being an incumbent no longer hurts performance significantly. In fact, it has a signifi-

Table 9. Understanding the effect of specialized complementary assets: determinants of market share, dependent variable = 1n (Market share). Sample includes only competence-destroying technological generations, $n = 154$

	Model 1	2	3	4	5	6
CONSTANT	4.82***	4.99***	5.07***	5.33***	5.66***	5.9***
	(0.44)	(0.38)	(0.52)	(0.42)	(0.38)	(0.42)
Number of Competing Products	–0.33***	–0.32***	–0.32***	–0.33***	–0.26***	–0.26***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Segment Growth	0.004	0.001	0.001	0.005**	–0.003	–0.003
	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
First Product	–0.34	–0.56***	–0.56***	–0.65**	–0.42***	–0.44**
	(0.24)	(0.21)	(0.21)	(0.24)	(0.20)	(0.20)
Incumbent	0.20					
	(0.22)					
Incumbent Complementary Assets Devalued*		–1.01***	–1.11***			
		(0.25)	(0.36)			
Incumbent Complementary Assets Not Devalued*		1.09***	0.99***			
		(0.22)	(0.33)			
New Entrant Possess Complementary Assets*			–0.12			–0.34
			(0.32)			(0.26)
Stock of Prior Experience				–0.014***		
				(0.004)		
Stock of Prior Experience Complementary Assets Devalued*					–0.008***	–0.012***
					(0.003)	(0.004)
Stock of Prior Experience Complementary Assets Not Devalued*					0.007	0.006
					(0.014)	(0.017)
Complementary Assets Devalued					–1.55***	–1.56***
					(0.28)	(0.28)
Adjusted R^2	0.40	0.55	0.55	0.46	0.61	0.61

Standard errors in parentheses; *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

cant and positive effect on market share, now resulting in a 0.99 per cent increase in share. So despite the technological disadvantage imposed by competence destruction, it appears that specialized complementary assets sheltered firms in the industry—being an incumbent did not handicap them as long as specialized complementary assets retained their value.

Specification 3 examines whether new entrants with related specialized complementary assets, in this case related market experience, had an advantage over those without them. If related specialized complementary assets are valuable, one would expect the dummy for new entrants with specialized complementary assets to have a significant, positive coefficient. It is, however, insignificant. Given that actual relatedness is difficult to measure, this result is not surprising. As Mitchell (1992) points out, the sales method for related products serving the same customer can vary substantially. In this case, it is not clear that prior experience selling printing ink to typesetter buyers provides an advantage in entering the typesetter market. The individual making the purchase decision for the products and the entire purchase process may be quite different. Unfortunately, more refined measures of relatedness were not available.

Specifications 4 through 6 substitute for the incumbent dummy variable with a more precise measure of the incumbent's prior experience—years in the prior technological generation. The results of using this measure are qualitatively the same as those obtained when using the incumbent dummy. Specification 4 examines the effect of competence destruction without controlling for complementary assets. In this case, 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. In specification 5, however, one sees that when the interaction with whether specialized complementary assets lose value is included, the significant negative effect only holds if both competence is destroyed and specialized complementary assets lose value. Each additional year of experience in the prior generation leads to a 0.01 per cent decrease in market share. Given that some firms spent over 80 years in the prior generation this small annual effect is consistent with the effect of the incumbent dummy, which led to about a 1 per cent decrease in market share. When specialized complementary assets remain valuable, the estimated coefficient is positive and no longer significant. Once more specialized complementary assets appear to be buffering incumbents from the effects of competence destruction. Consistent with the prior result (specification 3), when a related market experience dummy variable is added in specification 6, to evaluate the effect of related specialized complementary assets for new entrants, it is not significant.

Interestingly, the control dummy variable for whether complementary assets are devalued or not is significant and negative in specifications 5 and 6. This implies that, on average, market shares were lower in the generation where incumbent complementary assets were devalued. Since there was a great deal of successful new entry, the market apparently became less concentrated and more competitive, resulting in relatively lower shares.

CONCLUSIONS

This paper has improved our understanding of the process of creative destruction through an examination of over 100 years of technological and competitive history in the typesetter industry. The industry has undergone three waves of creative destruction, where competence-destroying technological change has shaken the industry. In only one of these three cases, however, were incumbents displaced by new entrants. Using a data base that includes sales, price, technical characteristics, and organizational effects for almost every product introduced by every firm in the industry between 1886 and 1990, this paper explores how the balance and integration of three factors—investment, technical capabilities, and specialized complementary assets—drove the commercial performance of incumbents vs. new entrants.

This study contributes to our understanding of creative destruction in two ways. First, it adds to the limited number of detailed longitudinal industry studies that have attempted to understand the role of multiple waves of technological change in shaping the competitive landscape. Studies of photolithographic alignment equipment (Henderson and Clark, 1990; Henderson, 1993), disk drives (Christensen and Bower, 1996; Christensen, 1993), and medical diagnostic imaging equipment (Mitchell, 1989, 1992) each suggest factors that influence the relative position of incumbents and new entrants. This study provides additional empirical support for some of their findings.

While a lack of investment is sometimes responsible for incumbent failure (e.g., Christensen and Bower, 1996), other times incumbents invest substantial amounts in new technology (Henderson, 1993). Incumbents in the typesetter industry invested overwhelmingly in each new generation of competence-destroying technology. Since each new generation was incremental in the economic sense, and ‘sustaining’ in that it met the needs of existing customers, this result is consistent with theoretical expectations.

Despite timely investments, both qualitative and quantitative analysis confirmed that established firms were handicapped by their prior experience in that their approach to new product development was shaped by that experience. The initial products developed by established firms were consistently inferior to those of new entrants. The need for both new technical skills and new architectural knowledge proved difficult for incumbents to manage. This result is consistent with findings in many industries (Cooper and Schendel, 1976; Majumdar, 1982; Tushman and Anderson, 1986; Henderson and Clark, 1990; Afuah, 1994).

Incumbents did not, however, necessarily suffer commercial consequences as a result of their inferior technological positions. When incumbent firms possessed specialized complementary assets (Teece, 1986) that retained their value despite the technological shift, these assets were found to buffer incumbents from the effects of competence destruction. Incumbents only suffered in the market when both competence was destroyed and the value of specialized complementary assets was diminished. This result is consistent with Mitchell’s (1989, 1992) findings in the medical diagnostic imaging industry.

In addition to providing support for prior findings, this study takes prior work one step further by explicitly examining how the balance and interaction among investment, technical performance, and complementary assets drives commercial performance. With the exception of Henderson (1993), most prior work has focused on one dimension or another, without attempting to disentangle their differential effects. By explicitly distinguishing among the three, this work helps to pinpoint which factors drive ultimate commercial performance. In the typesetter industry, the importance of specialized complementary assets was paramount, and an analysis of the effect of competence-destroying technological change that focused only on investment or technical performance and ignored the role of complementary assets would have led to misleading results. This work therefore highlights the importance of integrating multiple perspectives when analyzing competition.

While this work takes an important first step towards understanding creative destruction, 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.

Perhaps the most serious limitation of this paper is its treatment of incumbents as a class of firms without distinguishing between individual firms within that class. There is great variation in the performance of incumbent firms, and understanding that variation is crucial. There is evidence, for instance, that intraorganizational ecological processes can help firms to survive shifts in their external environment (Burgelman, 1991, 1994). In addition, one might expect that differences in 'absorptive capacity', a firm's ability to exploit outside knowledge (Cohen and Levinthal, 1990), might explain the ability of some incumbents to traverse shifts. The degree of organizational separation of new technology development can also play a crucial role in an established firm's technological performance (Cooper and Smith, 1992). Finally, differences in country institutional settings might also play an important role in firm performance (Porter, 1990). Levinthal (1992) suggests that differential selection environments may be responsible for the survival of some incumbents and not others, and different country institutional settings could be responsible for differential selection. Government subsidies may, for instance, make firms that might otherwise succumb to the competition of new entrants viable players. Further work exploring these issues should inform our understanding of creative destruction.

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APPENDIX: DESCRIPTION OF TECHNOLOGICAL GENERATIONS

Hot metal typesetters

The original typesetter technology, 'hot metal typesetters', was based on Ottmar Mergenthaler's invention in 1886 and dominated the industry for over 70 years. These machines were entirely mechanical and worked as follows. An operator entered text on a typewriter-like keyboard and molds of letters (called matrices) fell from a case into a row in the appropriate sequence. When an entire row was finished, molten lead was injected into the molds to form a 'line of type'. After the metal cooled, the lines of type with raised letters, called slugs, were ejected from the machine, and the matrices were recirculated. Slugs were then arranged in a frame for letterpress printing.

Analog phototypesetters

In analog phototypesetters, the metal mold of a character was replaced with a photographic image of the character. These images were often stored on a spinning film disk that carried multiple fonts. Using varying electromechanical mechanisms, these images were exposed onto film, generally with a xenon flash. The film was then used to create a printing plate for high-volume printing.

Digital CRT typesetters

As the name implies, digital CRT machines took the analog images of characters and digitized them. Characters could then be stored in electronic format on a magnetic disk. Instead of a xenon flash, a CRT was used to write a character onto film by alternating 'on and off' positions using vertical strokes.

Laser imagesetters

Laser imagesetters differed significantly from the CRT machines in that, rather than exposing just characters onto film, these machines could integrate text and graphics on the same page. Dots were written onto the page using a raster scan. This meant that rather than write out a character at a time using vertical strokes, characters and images were created by painting a set of horizontal strokes across a page. In addition, rather than use a CRT to expose the film a laser was used.