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REVERSING COURSE: COMPETING TECHNOLOGIES, MISTAKES, AND RENEWAL IN FLAT PANEL DISPLAYS

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Research summary: *The study explores renewal in a novel but understudied context—an era of ferment with competing technological options. It focuses on IBM's transition from market leadership in a failed path (plasma) to leadership in the emerging dominant technology (LCD) in the 1980s. Interviews and internal documents offer two primary factors explaining renewal at IBM. First, IBM Research had a hybrid structure that captured the benefits of both centralized and decentralized R&D. Second, middle managers shaped senior management cognitive frames to focus on business-related issues instead of specific technical issues, thus bypassing biases often resulting from failure. The study offers an integrated framework on what facilitates flexibility at the technology, organization, and decision-making levels. This flexibility helps firms survive a turbulent era of ferment.*

Managerial summary: *Firms facing technological uncertainty may need to recover from unlucky bets. But responding to failure is politically and organizationally difficult. This study explores how IBM recovered from its failed bet on plasma displays to lead the LCD display market. This study identifies six key factors, highlighting two. First, IBM's researchers received centralized funding, but could also receive funding directly from division managers. This structure helped preserve options and variety. Second, internal LCD champions focused on the business case for displays and not technology. This fostered technology agnosticism and helped avoid managerial biases from failure. For managers looking to use real options to maintain flexibility in an uncertain environment, this study offers clear suggestions related to design and decision making that can foster flexibility.*

INTRODUCTION

The dynamics of technological change—the emergence of a new technology that replaces an existing, dominant technology—are an important and popular research topic. This research addresses field-level dynamics of radical change (e.g., Tushman and Anderson, 1986), why incumbent firms struggle with change (e.g., Tripsas, 1997) and firm-level heterogeneity in response (e.g., Rothaermel, 2001). Such studies take a common form—focus on incumbent firms prechange and assess whether they succeed after the new technology dominates the industry.

What is typically absent is engagement with the *era of ferment*, defined as the period after the new technology emerges, but before standardization and commercialization. Anderson and Tushman (1990) are among the few exceptions, but they focus on field- and technology-level factors that drive variety and standardization timing. We know less about firm-level processes for how organizations adapt during the era of ferment. While commenting that "the firm and industry level dynamics in the [era of ferment] deserve attention from strategy, innovation, and entrepreneurship scholars," Moeen and

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Agarwal (2015) note that few studies have directly engaged with questions about the era of ferment.

This study identifies a tension confronting firms in an era of ferment. First, firms often have incentive to enter a new industry early to build industry-specific knowledge (Eggers, 2014), resources (Dierickx and Cool, 1989), and momentum (Miller and Friesen, 1982), creating the need to aggressively build a defensible position (Cabral, 2003; Lieberman and Montgomery, 1988). Second, eras of ferment typically feature the proliferation of technological variants with uncertain futures that complicate search processes (Kretschmer, 2008; Schilling, 2002). The term *dominant design* implies the failure of nondominant designs, and many early entrants in an era of ferment face the potential that investments result in failure (Garud, Nayyar, and Shapira, 1997). Such technological failures can be difficult for organizations to recover from (Eggers, 2012), which presents significant tradeoffs for firms facing an era of ferment. Should a firm enter early to support Blu-ray or HD DVD for high-definition movies, or wait until uncertainty has resolved? Lithium ion or nickel hydrate for batteries? GSM or CDMA for mobile phones?

Ideally, a firm could enter early to accumulate knowledge and momentum, but retain enough flexibility to shift quickly between technological paths (McGrath, 1997) and avoid biases from failed choices (Baumard and Starbuck, 2005). Given the plethora of uncertain technological options typically available during the era of ferment (Anderson and Tushman, 1990) and the potential dangers of making poor choices (Eggers, 2012), this study focuses on a simple research question: How can firms maintain organizational flexibility during an era of ferment? This provides important insights into how firms actually manage potentially competing options within the same firm. Given the paucity of research on the era of ferment, but the challenges created by competing technologies and high chances of failure, this study focuses on a single firm (IBM) that placed a significant technological bet during the era of ferment in flat panel displays, watched it fail, and then recovered to become the world leader in the competing technology that had destroyed its initial bet. As the flat panel display industry emerged (1960s–1980s) to supplant cathode ray tubes (CRT), early entering firms faced a choice—invest in liquid crystal displays (LCDs) or invest in plasma displays (or both). Most firms that initially supported plasma were unable to transition to LCD when LCD emerged as the dominant design in the mid-1980s. These inert early entrants included large, well-established firms from across the globe, such as Burroughs, Siemens, NCR, AT&T, and Sony. But IBM was among the early plasma supporters that did transition to LCD, and the speed and success of IBM's transition make it a worthy subject to uncover how firms can improve flexibility during an era of ferment.

Decision making and resource allocation in the era of ferment

To frame the underlying challenges of decision making and resource allocation when firms face competing options during the era of ferment, I begin with a basic model of strategic decision making (Figure 1a).[1] The model provides insight into why flexibility is important—failure is likely, and typical recovery processes are slow and uncertain. Figure 1(a) generalizes from decision-making models discussed by Mintzberg, Raisinghani, and Theoret (1976) and Schwenk (1984): The organization becomes aware of the need to make a decision, searches for potential solutions, selects a solution, and implements (allocates resources) to the chosen option.

In an era of ferment with competing technological options, firms may have to recover from making the wrong choice initially. Both Figure 1(b, c) include variants on this challenge. Figure 1(b) recognizes that, based on research on how failure affects subsequent decision making, the initial failure likely biases subsequent decisions to the point that the firm may never switch to the winning technology. Most notably, Denrell and March (2001) show in a model and Eggers (2012) shows empirically that the initial failure is likely to lead to risk aversion and retreat to better-known domains as the firm overreacts to the initial failure. Drawing proper inference from failure is a complicated sense-making process (Cannon and Edmondson, 2001), and most organizations demonstrate inefficient responses to failure (Baumard and Starbuck, 2005). Thus, the firm may simply abandon the failed domain instead of switching to the winning technology. Figure 1(c) suggests that during implementation of the first technology, the firm realizes

[1] Note that across all figures, the height of the boxes represents the level of activity or investment, while the width of the boxes represents time.

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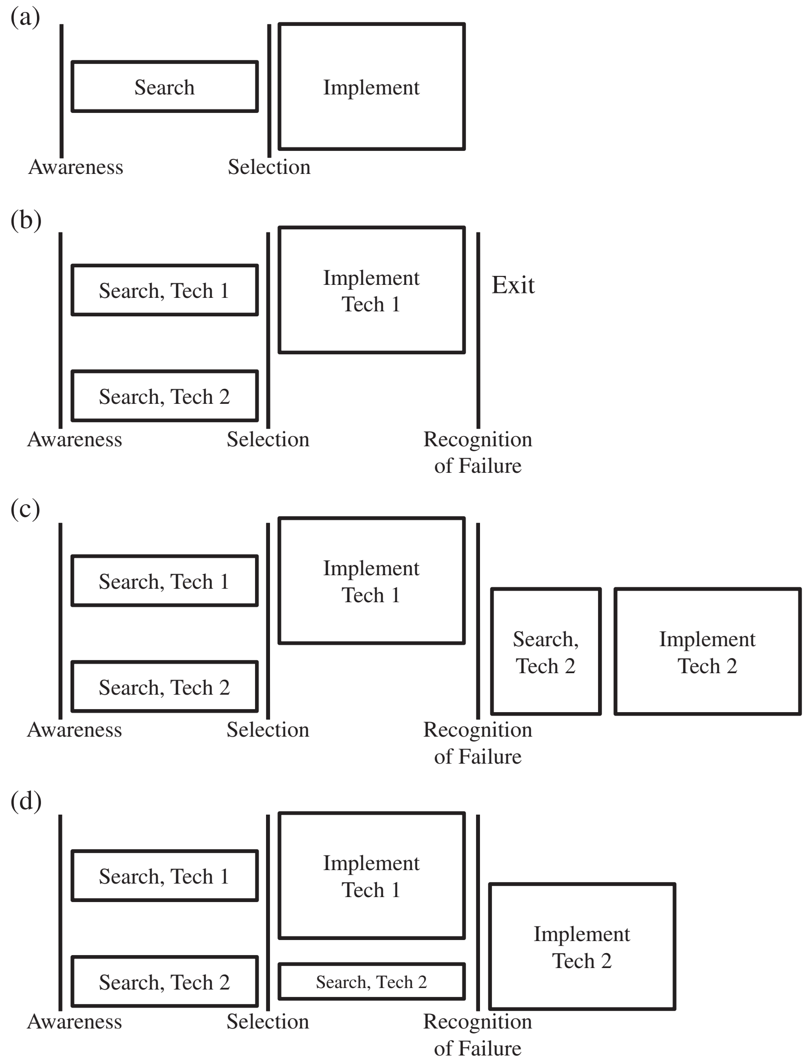

Figure 1. Four models of decision making. (a) Traditional model of strategic decision making (e.g., Mintzberg *et al.*, 1976; Schwenk, 1984). (b) Competing technologies and firm exit following failure of first choice (e.g., Eggers, 2012). (c) Traditional model with failure and reorientation to secondary choice. (d) Accelerated model with failure and reorientation to secondary choice. Note: Height of boxes represents level of activity; width of boxes represents time

its mistake, returns to the search process to assess the current state of the evolving technological landscape, and selects a new alternative. In Figure 1(c), the firm recovers from its failure, but the process is sequential and lengthy as the firm reinitiates search after abandoning the first choice. This leaves the firm behind competitors that initially chose correctly (Cabral, 2003).

Figure 1(d) shows a better solution with a modified renewal process. While the firm makes a definite selection initially, it does not completely abandon the search process for other alternatives. As a result, when the firm realizes that the initial choice is not succeeding, it quickly returns to the selection process, which results in a shorter overall adaptive process. Additionally, the detrimental effects of the first failure on the second selection process that could lead to Figure 1(b) are absent, so the second selection in Figure 1(d) is less likely to be biased.

This study investigates how firms follow Figure 1(d) instead of (b) or (c). First, how can a firm make a definite choice and yet maintain options should the choice fail? This question focuses on idea generation (Knudsen and Levinthal, 2007). Second, how can a firm avoid decision biases that typically emerge post-failure? This question focuses on biases in selection. Answers to these questions provide insight into how firms can improve flexibility during an era of ferment.

Contribution and fit with existing literature

This study is motivated by eras of ferment as a phenomenon. Eras of ferment frequently accompany significant technological transitions (Tushman and Anderson, 1986). As Figure 1 outlines, the costs of making mistakes in placing technological bets can be significant if the firm cannot quickly switch to the winning technology. So this study's focus on IBM's renewal begins to fill an important gap in our understanding of eras of ferment.

IBM's experience in flat panel displays offers two primary factors that drove its ability to adapt like Figure 1(d). First, managers focused on critical business problems (self-cannibalization of their CRT business and the creation of portable computers) instead of the technical details of LCD versus plasma, and that framing helped overcome risk aversion typically accompanying failure. This finding has implications for literature on managerial framing (Barr, Stimpert, and Huff, 1992), and specifically, for studies suggesting that the orientation of managerial framing is important for adaptation (Eggers and Kaplan, 2009; Tripsas and Gavetti, 2000). Second, IBM's R&D structure featured hybrid decision making. IBM was centralized in that there was a single research group, but it was decentralized in that resource allocation rights for exploratory research were pushed down in the organization. This finding has implications for research linking structure and innovation (Dewar and Dutton, 1986) as it provides insight into conflicting results supporting centralization (Argyres and Silverman, 2004; Siggelkow and Rivkin, 2005) versus decentralization (Bower, 1970; Burgelman, 1991). These factors provide four novel propositions about cognition and structure in the era of ferment that identify research opportunities.

This study contributes to three additional bodies of literature. First, the process of recovery from a failed technological investment is related to strategic renewal in that it involves the "refreshment or replacement of attributes of an organization that have the potential to substantially affect its long-term prospects" (Agarwal and Helfat, 2009: 282). Strategic renewal, however, typically deals with renewal after a fall from success (e.g., Kim and Pennings, 2009), which results in behavioral biases, including inertia (Miller, 1994; Miller and Chen, 1994) and competence traps (Leonard-Barton, 1992; Levitt and March, 1988). The flexibility shown by IBM in flat panel displays emphasizes the renewal process from a previous poor choice, which results in failure-induced biases (Denrell and March, 2001). Thus, both success and failure can lead to inertia in different ways and work on strategic renewal should consider both.

Second, IBM avoided irreversible commitment and maintained options for future investment, which relates to real options (McGrath, 1997). Most real options research lauds the benefits of limiting commitment, but provides little detail on how firms actually manage this politically difficult process. What research does explore the processes behind option management often emphasizes top-down initiatives to maintain a portfolio, what Burgelman (1991) terms an "induced approach." But IBM's senior management committed to one technology (plasma), while middle managers and research scientists led the subsequent renewal in LCD. Thus, IBM's move from plasma to LCD is an example of an autonomous, bottom-up approach to managing options and resource allocation (Burgelman, 1991). Burgelman (1994) provides one example of autonomous renewal at Intel with the shift from memory to microprocessors through a simple value-based heuristic. Intel, however, faced two established technologies sharing a constrained resource (foundry space), where resource allocation was decided based on the market's valuation of the products. In contrast, there is no market in the precommercialization era of ferment in IBM's story. The story is about technological uncertainty in which the firm faces competing technological options and maintains activity in both in case the initial choice fails. By providing insight into the processes by which IBM established and maintained those options, this study adds to our understanding of the implementation of real options.

Third, this study emphasizes the role of middle managers and extends research on middle managers and adaptation (Floyd and Lane, 2000; Taylor and Helfat, 2009) in two ways. First, it goes beyond the existing literature on issue selling by middle managers to suggest that not only can middle managers bring specific issues to top-managers' attention (Dutton *et al.,* 2001), but the way in which those issues are sold to senior managers can affect how senior managers approach the problem, and

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thus, how susceptible to failure-driven biases the final decision-making process may be (Eggers, 2012). In so doing, it links the literature on issue selling with that on the antecedents and adaptive importance of top-managerial cognition (Barr *et al.,* 1992; Gerstner *et al.,* 2013), an important link not often made. Second, by exploring a new context for middle-manager action (era of ferment), this study articulates a distinct role for middle managers to identify, fund, and develop backup technological options that preserve variety and options.

DATA AND METHODS

This study uses data from IBM's experience in flat panel displays from the 1970s to the 1990s as IBM switched from plasma to LCD. The data include hundreds of internal documents dated 1970s–1990s.[2] The documents range from briefings for senior executives to technical plans (see Appendix S1). I supplemented internal documents with publicly-available documents, including patents, annual reports, scientific articles by IBM employees and others about industry history (Alt, 1998; Brody, 1996; Depp and Howard, 1993; Howard, 1992; Kawamoto, 2002; McGroddy, 2001), a case study on IBM's JV with Toshiba (Matsui, West, and Bowen, 1997), and a book on the display industry (Murtha, Lenway, and Hart, 2001). I also conducted 17 interviews with 11 employees at IBM involved in the firm's plasma and LCD activities between 1970 and 2000. My subjects were the researchers and business leaders behind practically every IBM display project during the study frame. Interviews were initially open-ended and became more structured for subsequent interviews. I also interviewed 15 relevant people from similar firms and collected secondary data about dozens of other companies engaged in display research, both for context and for outside perspective on IBM's evolution.

Data analysis started with the basic tenets of grounded theory building (Glaser and Strauss, 1967/1999). I then used existing literature to explore how IBM's case differed from traditional views of inertial incumbents in the technological dynamics literature, and indeed, from the majority of other firms in the flat panel display industry. First, I built a comprehensive timeline of IBM's actions related to flat panel technologies. These events were categorized based on the type of event (e.g., task force formation, scientific discovery, resource commitment) and the identity of the players (junior vs. senior, R&D vs. product divisions). With data organized by event, I then identified important factors affecting the critical decision point for each event. This process produced a series of coded factors behind each decision. I then took the list of coded factors and looked for consistency across decision points (factors that influenced multiple decision-making processes), or which were especially key in a single decision-making point. This provided an initial set of explanatory factors. I then reinterviewed key informants with close familiarity with the factors and the key decisions in which they played a critical role, or identified new sources to interview. This allowed me to refine and articulate the underlying factors, understand the role they played in the renewal process, and develop an understanding of the broader importance of these factors. I then organized the refined set of factors in a hierarchical structure (see Figure 3), which allowed me to identify commonalities and linkages across factors. Finally, I discussed the factors and findings in detail with two sources that agreed with the framework.

By focusing on the flat panel industry, this study complements the relatively few flat panel studies. First, Spencer (2000, 2003) discussed how firms learned about different technological options from other firms, through conferences, published papers, and informal connections. Industry information was readily available, meaning that responding quickly to developments could be important for success. Second, managers perceived a great deal of risk in making irreversible commitments and sought external relationships to reduce firm-specific risk (Hoetker, 2005, 2006). Third, firms supporting the losing technology initially had a difficulty switching to LCD (Eggers, 2012), but that those firms looking to make the switch were not necessarily permanently disadvantaged versus early LCD adopters (Eggers, 2014). Each of these points—the availability of information about the success or failure of the different technologies, the importance of risk and external firm relationships, and the difficulties posed by technological trajectory failure—receives close attention below.

[2] The documents were obtained from interviewees, with most being provided by a former Director of IBM Research.

IBM AND THE EVOLUTION OF THE FLAT PANEL DISPLAY INDUSTRY

In 1964, two University of Illinois professors created the first plasma display.[3] The goal was a computer graphics panel. By 1968, Owens-Illinois (a glass manufacturer) licensed the Illinois patents to design displays for computer terminals. Soon after, firms in the United States (IBM, Burroughs, NCR, and Control Data), Japan (Fuitsu, NEC, and Sony), and Europe (Philips, Siemens, and Thomson) invested in plasma by licensing the Illinois patents, pursuing research programs, and/or investing in manufacturing. In 1971, Owens-Illinois introduced the first commercial product, a 12" monochrome graphics terminal (see timeline in Table 1).

Meanwhile, researchers at RCA demonstrated the first LCD in 1968.[4] Competitor Westinghouse was working on thin-film transistors (TFTs) that would eventually become a key component of LCDs. Yet, both American firms missed LCD opportunities by slowing development in the early 1970s. Instead, Japanese firms Sharp (a calculator in 1973) and Seiko-Epson (a watch in 1973) pushed forward with LCD. A number of Japanese firms (e.g., Hitachi, Matsushita) began manufacturing small LCD products in the 1970s, and researched larger, higher resolution panels. In the mid-1970s, firms such as Siemens, Marconi, and Brown Boveri invested in LCD research programs targeting large displays. Both technologies—LCD and plasma—were viewed as computer-monitor applications, and flat panels were vital for portable computers.

IBM part I – plasma displays

Monitors were an important product supporting IBM's computer businesses. In 1964, IBM introduced the first display terminal, the IBM 2260 with an integrated CRT allowing interaction with mainframes. By the early 1970s, terminals were a vital strategic and revenue-generating product. In 1985, display terminals accounted for more than $4 billion of IBM's annual sales (about 10% overall). Forecasts projected strong growth.

IBM's initial interest in plasma was to replace CRT terminals. IBM licensed the Illinois patents in 1969 and initiated commercialization efforts. IBM introduced its first plasma display in 1973 in a line of banking terminal products. The system used multiple panel sizes, from small teller panels to larger (12") banker panels. With commercial launch, IBM transferred control of plasma activities from IBM Research to the Terminals product division in Raleigh, North Carolina. IBM maintained leadership in plasma display research, publishing dozens of important scientific papers and receiving 86 plasma patents between 1968 and 1983 (second only to Owens-Illinois with 109). With this momentum and knowledge, IBM built a manufacturing facility in Kingston, New York, in the early 1980s, and in 1983, introduced the first 14" monochrome plasma panel, a device that displayed four times the information available on CRT terminals at that time.

Despite this progress, one researcher remembered that it was already clear that plasma "wasn't the right answer" long term. Manufacturing yield rates were under expectations, development took longer than planned, and the high price of panels limited the markets. According to the head of an internal task force, plasma panels were "too expensive compared to the cathode ray tubes … [because] the cost of making the plasma panel was simply higher than people had projected." Facing similar problems, Owens-Illinois abandoned plasma in 1977, and other early adopters soon followed. The future of plasma displays at IBM came to a head in 1983 when the Terminals division requested $40 million in funding for plasma displays. In response, management convened a cross-functional task force. The task force's official report concluded that the "plasma panel [would be the] clear winner only for large area display" and that "plasma technology should be managed for near term business return" and then discontinued. IBM continued making plasma displays until closing the Kingston plant in 1986.

IBM part II – liquid crystal displays

In recommending that IBM abandon plasma, the 1983 task force did not suggest exiting displays. Indeed, the task force called LCD "strategic" and claimed that "LCD will win in the long run" for computer monitors. While IBM had only

[3] A plasma display encloses a mix of gasses in tiny cells between two sheets of glass, and then uses electricity to create phosphorescent light.

[4] An LCD uses thin layers of electrodes to control a set of liquid crystals encased between two sheets of glass. The liquid crystals modulate the light from a backlight to create the image.

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Table 1. Timeline of flat panel display industry, 1968–1992

		Plasma		LCD	
	Other	External	IBM	External	IBM
1968		Plasma patents licensed to Owens-Illinois, IBM, Control Data, Fujitsu, NEC, NCR		RCA demos "crude" LCD prototype	
1969			IBM begins plasma work in earnest		
1970				First TN (twisted nematic) LCD patent	
1971		Owens-Illinois introduces first PDP product (12" display)			
1972					
1973			Introduce multi-panel banking system	First LCD calculator (Sharp) and watch (Seiko)	
1974				First AM LCD prototype (Westinghouse)	Alt, Pleshko write paper on passive matrix addressing limitations that kills LCD interest
1975			IBM introduces larger PDP displays	Dundee group performs aSi doping study that leads to strong aSi interest	
1976					
1977		Owens-Illinois abandons plasma			Started small AM LCD research activity in CA
1978					
1979	IBM introduces color CRT			aSi in TFT array for LCDs (U Dundee)	
1980					Momentum for LCD research restarts
1981	IBM introduces first PC				
1982			Kingston plant opens	First STN (super twisted nematic) LCD patent	First official LCD task force
1983		Sperry, Control Data, Burroughs, NCR abandon plasma	First 14" monochrome PDP (3290); PDP group requests add'l \$30–\$40 million; task force to assess PDP program; IBM unofficially ends PDP research	First color LCD prototype (Seiko-Epson); Seiko introduces 2" full-color LCD TV	
1984		Texas Instruments abandons plasma			IBM research hires two scientists specifically to focus on LCD; Internal task force labels LCD as "strategic" technology
1985	IBM ends CRT research	AT&T abandons plasma		First STN display panel (Brown Boveri)	
1986			IBM ends PDP manufacturing		Initiation of joint research w/Toshiba (2-year deal)
1987			Plasmaco purchases IBM PDP equipment	Laptops with STN displays hit market	
1988					DTI creates 14.1" prototype
1989					DTI's first fab opened at Himeji City (Japan) next to Toshiba STN plant
1990					
1991					P75 portable (\$18,000)
1992					First ThinkPad (Model 700C); DTI makes about 500k TFT LCDs

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exploratory research in LCDs underway in the early 1980s, the firm had previously worked with LCDs. Despite focusing on plasma in the 1970s, IBM continued to experiment with different display technologies, including electroluminescent (EL), e-beam, electrophoretics, electrochromics, and liquid crystals. An IBM Research paper (Alt and Pleshko, 1974) demonstrated size limits of passive matrix displays (then the LCD standard), suggesting that they would not be appropriate for computer displays. This paper helped convince IBM to reduce its LCD research. But a series of technological advances, as well as the viability of LCD watches, sparked reconsideration of LCD in the early 1980s.[5]

Three events spurred increased attention to LCD. First, a task force scientist was at the 1983 Society for Information Display conference and saw Seiko-Epson's prototype for a 2" full-color LCD TV. He related: "I went and made a pitch .... [T]his could really be the key to the future of flat panels. And IBM needs to start paying attention. And what you should do is give me some money to start a program." Second, IBM introduced full-color terminals in 1979, and the sales success convinced managers of color's importance. IBM's human factors studies also showed that "you really needed color" to meet user expectations. IBM documents post-1983 list "full TV color" as a "key strategic requirement." With respect to plasma, a lead display scientist recalled that, "we knew there was probably a road to color but it was going to be difficult." A 1984 internal report noted that there was "no good color version" of plasma on the horizon. Seiko's 2" LCD screen was full color, and the technology showed potential for larger screen sizes. Finally, IBM had introduced the personal computer in 1981, and executives were eyeing the potential of "portables" (laptops). The potential for portable computers accentuated the importance of weight, durability, and power consumption when considering flat panel displays, and it appeared that LCD would best deliver on these criteria.

IBM did not immediately invest in LCD. In 1984, IBM hired two LCD scientists and convened additional task forces. The big move came in 1986 when IBM signed a two-year R&D alliance with Toshiba focused on color active matrix LCDs. IBM settled on Toshiba, in part, because "they were probably hungrier than others" (according to the VP of Research), and in part, because Toshiba had built the largest prototype. The relationship initially focused on proving that the smaller (2"–3") LCD TVs could scale, and moved to the creation of a 14" full-color prototype. In 1988, the two firms created Display Technologies (DTI) as a JV with manufacturing in Himeji (Japan). By 1991, DTI created the screen for the P75 portable, and in 1992, for the first IBM ThinkPad. In 1992, DTI produced 500,000 LCD panels for use by IBM and Toshiba as well as selling externally. This generated $220 million in sales, 18 percent market share, and increasing profitability as costs dropped.

Patent records (Figure 2) demonstrate IBM's "about-face." The left axis shows the share of IBM's flat panel display patents in plasma (solid line) and LCD (dashed line). The right axis shows the global count of patents applied for in both plasma (black area) and LCD (gray area) technologies. Through the early 1980s, industry-wide patenting in LCD and plasma were roughly equal. Around 1983, firms began patenting in LCD at a rate not mirrored in plasma. The two lines demonstrate both the extreme nature of IBM's decision making (the firm was almost completely plasma-focused early and almost completely LCD-focused later), and that the shift for IBM happens around 1982. Thus, even though IBM had committed to plasma, it switched to LCD with almost no lag to the overall market.

IBM's unique history in flat panel displays

While IBM successfully switched from plasma to LCD, most other plasma supporters did not. Table 2 provides information on the 10 firms that licensed plasma patents from Illinois as well as other firms with significant early patenting in plasma (excluding firms with more early LCD than plasma patents). The table summarizes a few key historical takeaways. First, IBM was an early leader in plasma as evidenced by its dominant patent position and status as the leading manufacturer. Second, of the early plasma supporters, only four went on to manufacture LCD panels, and one of those (Philips) was a relative latecomer after a protracted turnaround. Thus, IBM's story is relatively unique in this industry in terms of its ability to recover from the failed plasma investment, making the firm

[5] The major technological advances included work by Peter Brody at Westinghouse in the use of active matrix TFTs for LCDs, and work by Toshiba researchers in the use of amorphous silicon (aSi) as a lower temperature (and therefore, lower cost) manufacturing method for LCDs.

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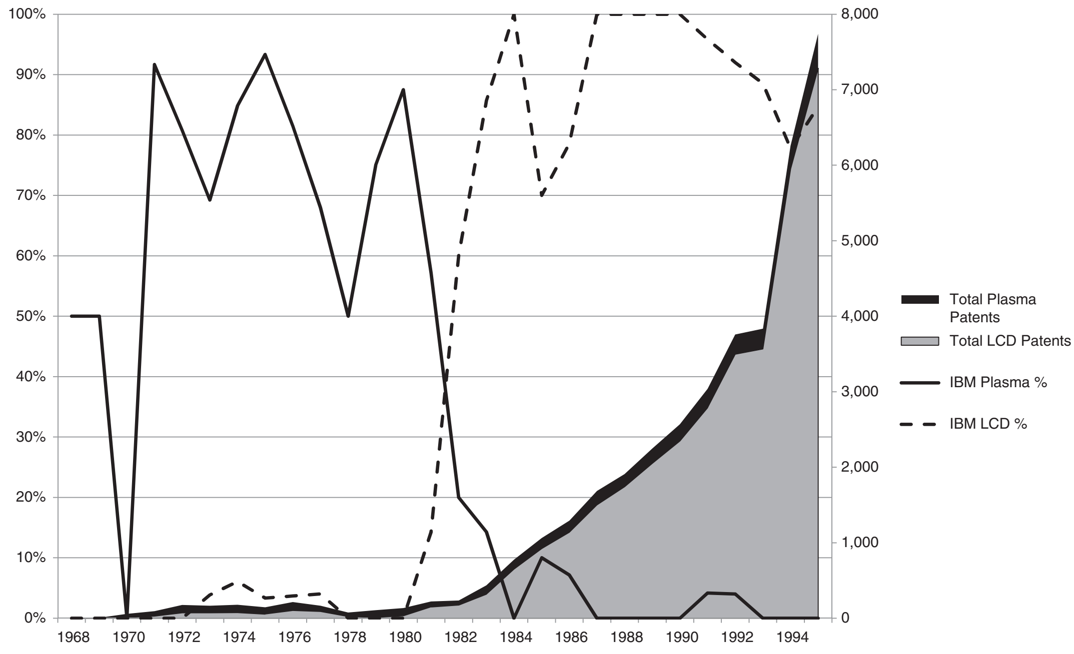

Figure 2. IBM and total industry LCD and plasma patents, 1968–1995

an excellent study subject. Third, IBM was one of the latest firms to abandon plasma, ending research in 1983 and closing manufacturing in 1986. Thus, the secret to IBM's success was not in recognizing the failure of plasma earlier than other firms (Guler, 2007), and in fact, the firm succeeded despite its escalation of commitment to plasma (IBM was one of the last firms to build plasma manufacturing capacity for computers). Fourth, while some firms faced liquidity constraints (e.g., Burroughs, Control Data, Thomson), many were large and successful throughout the entire period, suggesting that IBM was not necessarily successful because of its size or liquidity to fund LCD research.

UNDERSTANDING IBM'S FLEXIBILITY AND RECOVERY

Prior research on strategic renewal (Crossan and Berdrow, 2003; Danneels, 2011; Kim and Pennings, 2009) studies previously successful companies struggling to reinvent themselves as their business models are attacked by a new technology. The case of IBM, while similar, is also distinct—instead of renewing from fading success, IBM faced the challenge of recovering from a single, costly misstep in a newly-emerging industry. Figure 1 shows that a smooth recovery (d vs. b or c) requires two key changes. First, IBM could not wait until plasma's failure to explore LCD, but needed to invest in alternative technologies despite the firm's commitment to plasma to keep options open. Second, IBM had to overcome failure-induced decision-making biases that would likely have led to exit from flat panels instead of resource allocation to LCD (Denrell and March, 2001). Avoiding these two traps provided the flexibility for IBM's renewal.

Below, I focus on the two most novel and interesting factors that contributed to IBM's flexibility as well as mentioning other contributory factors. These factors, and the overall structure of the constructs derived from the data, are summarized in Figure 3.

Hybrid R&D structure

The importance of maintaining technological options manifests in two ways for IBM. First, if IBM Research was completely committed to plasma then LCD's improvements in the 1980s would have been ignored or seen as a competitive event. IBM would have escalated commitment to plasma (Guler, 2007). Instead, IBM Research still viewed LCD as "on the menu" as an option. Second, to build support for LCD, researchers needed scientific knowledge and resources the firm

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Table 2. Early plasma supporters

Name	Nation	U Illinois Licensee	Pre-1983 patents Plasma	Pre-1983 patents LCD	Plasma Exit	Post-1990 LCD Mfg
Owens-Illinois	United States	Yes	109	7	1977	
IBM	United States	Yes	86	6	1986	Yes
Burroughs	United States	Yes	78	1	1983	
Fujitsu	Japan	Yes	67	3	na	Yes
Siemens	Germany		53	36	na	
Philips	Netherlands		41	12	1981	Yes
NEC	Japan	Yes	20	10	na	Yes
NCR	United States	Yes	19	2	1983	
AT&T	United States	Yes	19	11	1985	
Oki Electric	Japan		15	0	na	
Control Data	United States	Yes	13	0	1983	
Sony	Japan		13	6	1984	
English Electric Valve	United Kingdom		12	0	1987	
Thomson	France		12	14	1981	
Ferranti	United Kingdom		11	0	1978	
AEG	Germany		10	15	1984	
Sperry	United States	Yes	9	0	1983	
NHK/Japan Broadcasting	Japan		9	0	na	
Texas Instruments	United States	Yes	6	15	1984	

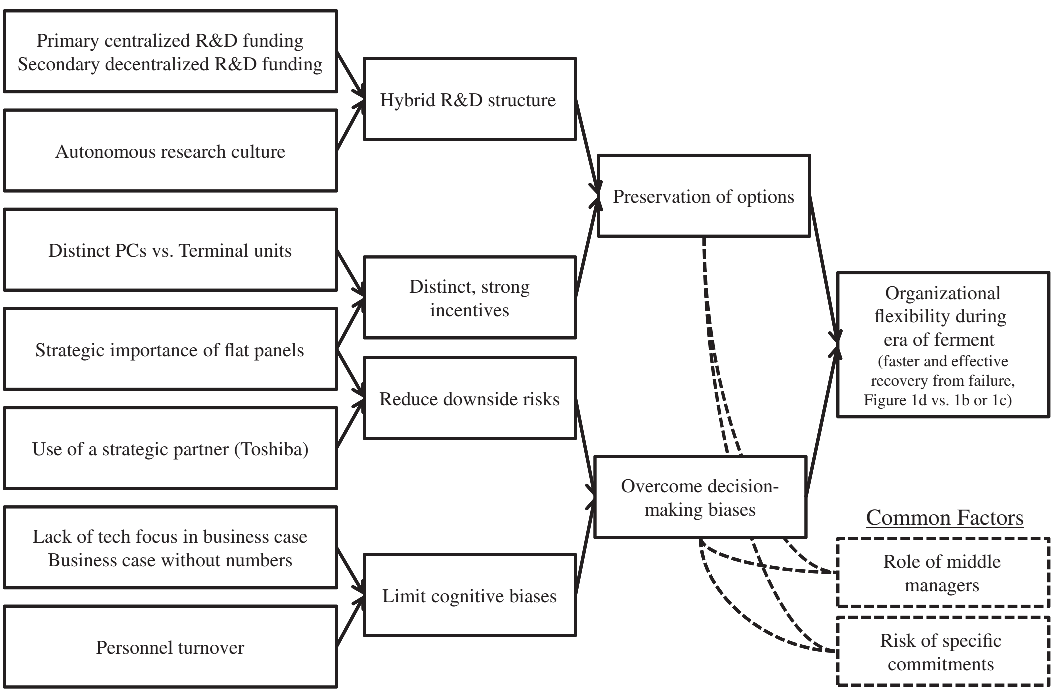

Figure 3. Key findings on IBM's renewal

lacked to build prototypes that helped convince stakeholders. As a senior R&D manager noted, those prototypes "just melted the execs." The key factors that helped IBM Research build a technological competence in LCD even after investing in plasma were IBM's culture, its structure, and the strategic importance of flat panel displays. These factors enabled researchers at IBM to investigate LCD enough that it remained a viable option.

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The structure of research at IBM played a vital role in helping preserve technological flexibility. IBM is often seen as highly centralized with tight internal controls (Gerstner, 2002). In terms of R&D, this characterization is only partly true. As opposed to dispersed R&D in each division, IBM had a single centralized R&D unit.[6] Prior research suggests important benefits from centralized R&D. First, "firms in which R&D activities are centralized tend to pursue R&D that has greater impact on future technological development, and spans a broader set of technological domains, than do firms in which R&D activities are decentralized" (Argyres and Silverman, 2004: 954). Centralization reduces transaction costs that might make innovations with multidivisional implications difficult to manage (Argyres, 1995). As a result, the firm is more likely to pursue projects that offer firm-level benefits, irrespective of whether they offer sufficient benefits for any single existing division. This is important at IBM because it was initially uncertain where flat panel displays would be most valuable—in Terminals or the emerging Personal Computing division. Second, centralized R&D can help firms overcome inertia and the preference for local search (Helfat, 1994). When R&D is handled by divisions, division managers with close relationships with existing customers may be beholden to existing technologies (Christensen and Bower, 1996), and may be less likely to pursue opportunities in new technologies than corporate managers (Galunic and Eisenhardt, 2001). Similarly, Siggelkow and Rivkin (2005) show that centralized firms are better able to adapt to environmental turbulence. Thus, centralized R&D likely helped IBM be open to pursuit of flat panel displays initially as flat panels threatened cannibalization for the existing CRT business.

Despite these advantages for centralized R&D in terms of cross-divisional projects and overcoming local search biases, there are drawbacks to centralized R&D. Centralized R&D may lead to top-down innovation initiatives instead of bottom-up innovation that is more responsive to local conditions and changing market factors (Burgelman, 1994). This lack of connection with customers may lead to innovations that cost more than the value that they create, and links between R&D and marketing are important to foster valuable innovation (O'Connor and DeMartino, 2006). Prior research suggests important links between a decentralized structure and innovation (Pierce and Delbecq, 1977; Shepard, 1967) as decentralized firms are better able to leverage specialized knowledge for decision making (Burgelman, 1991; Eisenhardt and Bourgeois, 1988). For IBM, we would expect that centralized R&D would focus its efforts only on plasma once plasma was selected. This would speed IBM down the plasma learning curve, but eliminate opportunities in LCD, thus limiting the ability to sustain variety and increase flexibility in the case of an error. This variety-limiting drawback of centralized R&D structures has not previously been identified in the literature. The drawback is most relevant for technological competition in the era of ferment, which leads to the first proposition:

> *P1: In an era of ferment, centralized organizations will tend toward focusing on a single potential answer, which increases the risks for the firm if the chosen option fails.*

The curious fact about IBM Research was that it was neither decentralized nor centralized, but hybrid in two ways. First, decentralized early research funding was available. Most funding for IBM Research came from the department's internal budget, which was derived from a "tax" on the product divisions. This funding was centrally dispersed by the corporate VP of Research. In addition, IBM required product divisions (semiconductors, terminals, mainframes, etc.) to put aside a portion of their budgets to fund IBM Research projects that the division believed in and approved. To receive funding, research managers approached product managers and pitched "joint programs" in which both research and division funding would be used for research efforts. In flat panels, much of the mid-1980s research budget for LCD panels came from joint programs with the Personal Computing Division. Thus, there was an internal market for R&D funding that was accessible without executive-level approval, and this market played a key role in maintaining technological variety.

Second, IBM scientists had a great deal of autonomy in how they chose projects. During the 1980s, IBM Research believed strongly in the right of scientists to work on projects of their own choosing, as opposed to working on centrally-designated

[6] IBM had research arms in different locations and countries, but these were not organized by division.

projects (Bhaskarabhatla and Hegde, 2014).[7] This created an informal decentralization as scientists were hired for long-term potential instead of a specific project, and were then given freedom to seek projects they found appealing. In this respect, the decentralization of control for research scientists can be seen as a cultural factor that helped to preserve potential technological flexibility. Scientists still needed funding to move past basic scientific research, and thus, the formal structural aspects noted above played a key role. But the effectiveness of these formal processes around funding were enhanced by the informal decentralization of IBM Research.

As a result, even while IBM focused on plasma in the 1970s and early 1980s, all work on LCDs did not cease. IBM continued LCD research in New York, the United Kingdom, and San Jose. When the Personal Computing Division increased in power, and simultaneously, the firm's plasma efforts began to stall, the hybrid nature of R&D at IBM facilitated the ability of scientists to get research funding from the Personal Computing Division to fuel work on LCDs. As the deputy director of IBM Research stated, it became a process of "getting together with the product division and agreeing on some things to pursue." Without the centralized aspects of IBM Research, LCD proponents might not have had access to the knowledge and experience of scientists who had done early stage work on plasma. But if IBM Research had been wholly centralized, then continued interest in LCD after commitment to plasma would have been impossible. Thus, the hybrid nature of IBM Research played a key role in helping IBM quickly and efficiently shift resources from the failed path of plasma to the more successful path of LCD.

This study's central finding on structure—that a centralized research center funded in a decentralized manner helped IBM recover from failure and maintain flexibility—provides an answer that integrates these two perspectives. Studies promoting centralization either explicitly (Siggelkow and Rivkin, 2005) or implicitly (Argyres and Silverman, 2004; Lerner and Wulf, 2007) focus on search, where the ability to coordinate needs across divisions is beneficial. This perspective aligns with Knudsen and Levinthal (2007) about the alternative generation process. By contrast, studies promoting decentralization largely point to the reliance on specialized knowledge from middle managers in the resource allocation process (Burgelman, 1991), which is closely tied to selection. That different structures may be more or less appropriate for different types of innovative activity (search and selection) echoes prior work (Dewar and Dutton, 1986) and presents a variation on contingency theory (Lawrence and Lorsch, 1967). In this case, the appropriateness of the structure depends on the aspect of the task. This structure also points to the benefits of centralized R&D, while still maintaining close ties with the product divisions to improve the marketability of innovative outcomes (O'Connor and DeMartino, 2006). Thus, the story of IBM suggests that a hybrid research organization, with centralized research to facilitate new market exploration, but with a decentralized selection and funding process that capitalizes on an internal market for ideas, can help organizations recover quickly from failed technological paths by preserving flexibility. This finding complements Burgelman (1994), who focuses on the idea that external market forces helped set internal "prices" within Intel and facilitated the switch to microprocessors. In this case, flat panel displays were in a precommercialization phase, and so there was no external market; but by providing capital for seed funding to middle and senior managers across a variety of product divisions, IBM was able to create a sort of internal market for ideas that facilitated flexibility.

> *P2: A hybrid R&D structure—with centralized research to facilitate nonlocal exploration but with mechanisms for decentralized project selection and funding via a market mechanism—can both facilitate focus on a single technology while preserving variety that maintains options.*

Managerial framing

The second part of IBM's story involves making LCD commitments in the context of plasma's failure. Many informants discussed the hurdles raised by plasma's failure, exemplified by this quote from an IBM Research scientist:

> I mean naturally you are always dealing with past failures. "Why is this not like this? And,

[7] Both aspects of decentralization—seed funding and scientist autonomy—were removed in the early 1990s when IBM pushed toward more cost-effective research and increased patenting.

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> oh wait, this story sounds good but so did the plasma story. Look what they made us do. Look what they sold us." … Well [the plasma investment] was basically scrap and move on . . . . And so the technical management was therefore more skeptical and more demanding of proof because they had been fooled. So that probably raised the bar for us.

This aligns with research suggesting retreat from failures in new domains for the organization (Denrell and March, 2001; Eggers, 2012), and presented a significant challenge for LCD adoption.

The most interesting factor contributing to IBM overcoming these biases involves how managers viewed the LCD choice, or more accurately how proponents framed the LCD choice when speaking with managers. A systematic review of internal documents presented to senior management by LCD proponents showed that presentations did not open with the pros and cons of the specific technology. Instead, documents focused on the importance of terminals, PCs and laptops for IBM and how flat panels were vital to that success. The best example is a 1985 business case presented to the PC Division head. The document opens with "flat panel Displays" and lists potential applications, such as "TV on the wall, portable TVs, terminals (military), low-bulk desktop terminals, rugged displays, portable computers," with no mention of specific technologies. The document then details key success factors by market segment, and when addressing terminals and personal computers highlights the importance of these markets for IBM with figures on sales and growth rates. The next page lists technologies, including everything from plasma to LCD to electrochromics. The document then matches each technology to IBM's key success factors and shows that, for markets vital to IBM, LCD is the only viable option. All executive presentations were similarly formatted, with no significant mention of specific technologies until at least halfway through.

Thus, instead of focusing on technological issues in trying to persuade executives, LCD proponents kept managers focused on the business case for flat panels. One scientist talked about "the laptop problem" and how IBM "wanted to be a laptop company," while another noted that the LCD display "was the thing that allowed you to have the laptop in the first place." When one executive, lamenting the uncertain nature of flat panel technologies and the firm's failure in plasma, suggested "giving up on the portable business completely," the argument was made that (related by the deputy director of research):

> "If you're not in portables, you're not going to be in personal computers." … And that scared everybody into, "Well we better, you know, we can't fail. We've got to make this, this portable computer work because we're already in the PC business and we don't want to give it up."

In summarizing the LCD case made to executives, the VP of Research remembers that, "[i]t was very much a strategic business case. It didn't even have numbers . . . . A lot of it was not even about the technology at all." LCD proponents focused not on technical issues, but on the product markets the firm wished to serve. This business case focus increased what practitioners call "technology agnosticism" and made managers flexible in their thinking, thus decreasing biases from plasma's failure.

Innovation research on senior managerial framing suggests that how executives frame innovation questions has an impact on whether they are endorsed (Barr *et al.,* 1992; Gilbert, 2006; Kaplan, 2008a, 2008b; Tripsas, 2009). The central point is that the orientation of managerial cognition and attention matters for action, similar to Cho and Hambrick's (2006) definition of *attentional orientation* as "the degree of attention paid to some category of stimuli" (p. 455). Prior research has shown that managerial focus toward existing technologies and routines (Leonard-Barton, 1992; Tripsas and Gavetti, 2000) restricts the ability to innovate flexibly, while managerial focus on a new technology speeds adaptation (Kaplan, 2008a).

What is instructive about the IBM case, and is only loosely discussed in the existing literature, is the use of a flexible, business-case oriented framing. LCD supporters used a business-case framing, choosing not to promote LCD specifically, but to emphasize the need to solve a business problem. Once proponents established PCs as an important business that would be at risk if the firm did not act, they then argued for LCD as the only viable solution. Set in the context of the era of ferment with competing technological options, this technology-agnostic framing provides insulation versus the failure of any given technological choice by diverting attention from the failure and decreasing resistance to investments in a different technology. Managerial focus is on long-term objectives, which emphasized the downside risks of taking no action by highlighting the stakes at risk (e.g., IBM's terminal and PC businesses). This framing diminishes the importance of technical considerations. IBM built organizational momentum toward flat panel displays without focusing on a specific technological solution, and thus, easily switched from plasma to LCD. The experience of IBM suggests that business-case framing may be an important part of surviving the era of ferment and maintaining technological flexibility even in the face of failure. The failure of corporate investments in new technologies can often lead to retreat and threat-rigidity bias even if the opportunities are significant (Eggers, 2012; Staw, Sandelands, and Dutton, 1981). If top managers fixated on the plasma failure, they would have been unlikely to approve investment in LCD. As a result, organizational processes that help overcome failure-driven biases are important to survival and adaptation in the era of ferment, when technological competition and wrong choices are common.

The importance of the business-case framing is related to two findings in the cognition literature. First, Eggers and Kaplan (2009) emphasize the role that managerial attention toward the affected industry played in spurring adaptation. As industry framing relates to a business-case framing, this prior finding aligns with this study. Second, Furr (2010) shows that an "outward focus"—a managerial frame focused on issues external to the firm such as customers and the industry—increases technological flexibility. Thus, a core contribution of this study is to suggest that a business-case framing increases flexibility and aids adaptation through the era of ferment more than a technology-specific framing, which increases risks should the choice be incorrect.

P3: A business-case-oriented framing, as opposed to a technology-specific framing, limits exposure to biases from previous failures that affect subsequent decision making.

Importantly, this framing in IBM links the antecedents of top-managerial cognition (Gerstner *et al.,* 2013) with the middle-manager literature on "issue selling" (Dutton and Ashford, 1993). In fact, a study of middle-manager efforts to frame issues for top management showed that middle managers frequently use business plans to sell ideas to senior managers (Dutton *et al.,* 2001: 722). Issue selling helps "shape the strategic agenda by influencing which issues come to the attention of top management," and "how issues are packaged or framed … [has] a significant impact on the effectiveness of issue selling" (Wooldridge, Schmid, and Floyd, 2008: 1203). The idea that how middle managers package, frame, and present ideas to senior management has implications for the likelihood of the ideas being adopted is central to issue selling (Dutton and Ashford, 1993). This study of IBM extends the idea that middle managers will have an effect on the organization's ability to adapt (Huy, 2002; Taylor and Helfat, 2009) by focusing on how the specific selling techniques used at IBM alleviated potential managerial biases. This middle-manager role is related to Floyd and Lane's (2000) view of middle managers as championing strategic renewal. IBM's middle managers did more than simply direct top management's attention to a specific issue, but they also shaped the cognitive frames that top managers brought to understand that issue. By framing the flat panel discussion as being about the business case and not the specific technology, IBM's middle managers were able to avoid a top-management frame around the failure of plasma, and instead, foster one about the potential of LCD. While the middle-manager issue-selling literature has often suggested that these efforts can affect the mental frame used by senior managers (Dutton *et al.,* 2001), this idea has not been linked explicitly to the literature on top-managerial cognition (Barr *et al.,* 1992; Kaplan, 2008a). The top-managerial cognition literature has begun to show greater interest in the antecedents of top-managerial cognition (e.g., Gerstner *et al.,* 2013), but has not discussed the possibility that middle-manager action would have meaningful impact. This study explicitly links these two literatures, especially by recognizing that the era of ferment and the potential for making failed technological investments create the potential for bias among top managers, which accentuates the importance of the ways in which middle managers sell decisions to senior managers.

P4: An important antecedent of the direction of top-managerial cognitive attention is the

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issue-selling approach used by middle managers to present the idea to senior leadership.

Other factors in IBM's renewal

While structure and framing both played central roles in IBM's transition from plasma to LCD, they were not the only factors. Two other factors affected IBM's ability to preserve technological flexibility. First, the fact that there were distinct personal computing and terminals units—and that plasma was attached to terminals—increased the likelihood that there was a significant difference of opinion about which technology might be successful, and enough funding to fuel research. Second, the strategic importance of flat panel displays to terminals, PCs, and laptops ensured that any reasonable idea would be funded. This second finding is in line with prior research documenting that strategically important markets are the ones most likely to be entered (Helfat and Lieberman, 2002; Mitchell, 1989).

In terms of IBM overcoming failure-induced decision-making biases, there are three additional factors. The first is the strategic importance of flat panel displays already noted above. This importance dramatically increased the costs of doing nothing, and ensured that a solution with a viable business case would receive consideration. Second, by working with Toshiba instead of entering LCDs alone, the LCD proponents reduced risks for IBM. The use of alliances to acquire new knowledge (Khanna, Gulati, and Nohria, 1998) and spread risk (Hamel, Doz, and Prahalad, 1989), especially in new and uncertain industries (Eisenhardt and Schoonhoven, 1996), is well documented. Each of these two points likely made the financials in any business case more attractive for IBM. Finally, the significant time period between the initial plasma decision (1969) and the decision on LCDs (1986) ensured that few middle or senior managers were involved in both decisions, and thus, the biases of prior failure would diminish.

DISCUSSION

This study explores how IBM flexibly navigated the challenging dynamics of an era of ferment with competing technologies. The importance but lack of research on eras of ferment (Anderson and Tushman, 1990; Moeen and Agarwal, 2015) represents the most important contribution of this study. IBM's initial failed investment in plasma made its shift to LCD technology all the more remarkable. This study focused on two contributing factors as important and theoretically rich. First, IBM's research activities had a hybrid structure, both formally and informally. There was a single central research division that helped facilitate entry into new technologies, but IBM avoided the risks of centralized research by exploiting an internal market mechanism for research funding that allowed heterogeneous opinions to receive support and thereby preserve flexibility. Second, LCD supporters framed the discussion not around specific technologies, but around the business case. This framing, as opposed to a technology-specific framing, helped the firm avoid biases that affect decision making after a failed investment.

As shown in Figure 3, these processes share important commonalities that merit further attention. First, both emphasize the role of middle managers in navigating technological failure and the era of ferment. Middle managers possess heterogeneous opinions (Floyd and Lane, 2000; Wooldridge and Floyd, 1990), and this heterogeneity allows the internal market for research ideas to function as a means of preserving variety as different managers sustain their preferred technological options (Burgelman, 1983, 1991). Interestingly, the role of middle managers as champions of a secondary, competing option (LCD) to the organization's initially adopted preference (plasma) may help to explain why middle-manager involvement is beneficial for organizational performance, but middle-manager agreement with each other and with senior management is not related to performance (Wooldridge and Floyd, 1990). By disagreeing with senior management during a time when there is a great deal of uncertainty regarding technological evolution, middle managers can help to preserve variety. This disagreement creates short-term inefficiency, but this fallback insurance may prove important to successful navigation of the era of ferment. Middle managers also play a key role in framing any given request for support from senior managers (Dutton and Ashford, 1993; Dutton *et al.,* 2001), and therefore, shape the cognitive frames of senior managers. This links the middle-manager issue-selling literature with the top-managerial cognition literature (Barr *et al.,* 1992) as the actions of the middle managers become antecedents of top-managerial frames. At IBM, this importance of middle managers may have been driven by IBM's

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policies on employment—at that time, there was virtual lifetime employment, which meant that the risks of being wrong for a middle manager were limited (increasing heterogeneous support for different ideas). This employment relationship created the need for variety to maintain progress, making retrenchment and retreat nonviable. As a result, IBM's middle managers played an important role, and the role of middle managers in navigating technological change merits continued exploration, ideally through multilevel work linking technologies with middle and top managers (Wooldridge *et al.,* 2008).

Second, both structure and framing involve the risks of specific commitments in a time with uncertain technological options. For structure, the hybrid structure that IBM adopted is a mechanism to avoid irreversible commitment to a potentially failed technological path through the preservation of variety. This splitting of investment across multiple paths creates inefficiencies as many paths will never be followed. But given the potential gains in flexibility from preserving variety, the benefits become clear in specific contexts. For cognitive framing, the risks of commitment are clear as a case made all about a technology becomes difficult to separate from the technology itself should that path fail. As a result, keeping a business-case-driven cognitive frame fosters technological agnosticism. Given the risks of being wrong when dealing with competing technologies, factors that limit commitment and preserve variety are important. IBM's story offers a complementary view of option preservation that is distinct from the top-down view of option portfolios in many theoretical studies (McGrath, 1997), and from Burgelman's bottom-up but market-driven process at Intel (Burgelman, 1994). IBM's experience features technological uncertainty with no market feedback (being pre-commercialization). IBM's research structure provides a distinct example of how firms can use bottom-up mechanisms to maintain flexibility and reduce technological commitment. This generates insight into how firms actually manage the real options process to preserve flexibility.

While this study focuses on IBM, there are interesting comparisons with other flat panel firms, specifically other early plasma supporters in Table 2. Owens-Illinois's failure to adapt was likely due to the lack of a business imperative to succeed—the firm viewed displays as a potentially profitable diversification move away from low-margin glass products, but was unwilling to continue when plasma failed. Sony, by contrast, had a significant incentive, but had been unable to build any knowledge in LCD. Executives at Sony believed they would be unable to catch up with LCD pioneers, so Sony focused its R&D efforts on a potential replacement technology for LCD (organic light emitting diodes, or OLED). Many other firms had fully centralized R&D activities, as opposed to IBM's hybrid structure, which may have prevented them from responding as flexibly to the changing technological environment. Even those other firms that successfully adapted offer instructive stories—both Philips and NEC only switched years later through partnerships (Philips with LG in 1999, NEC with Mitsubishi in 2000), and Fujitsu transitioned through relatively autocratic decision making by senior managers, but never played a significant role in the LCD industry.

Overall, this study fills a phenomenological gap in our research: How can firms be more flexible during an era of ferment? This question recognizes the uncertainty posed by competing technologies as well as the potential for failed investments that bias subsequent decision making. As a result, it contributes to the limited but growing literature focused on firm strategy in eras of ferment (Eggers, 2014; Moeen and Agarwal, 2015), and provides granular information about one firm's adaptive journey. From a theoretical perspective, this study both draws on and contributes to four distinct strands of literature. First, by articulating the costs and benefits of centralized, decentralized, and IBM's hybrid R&D structure this study expands on work on innovation and organizational structure (Argyres and Silverman, 2004). Second, the flexibility benefits that IBM derived from maintaining managerial focus on the business imperative and not a specific technology provides a novel way to think about the importance of the direction of managerial cognition for adaptation (Kaplan, 2008a). Third, this study expands on the literature on issue selling (Dutton and Ashford, 1993) by suggesting that selling efforts by middle managers not only bring issues to executive attention, but also shape how executives think about those issues. Finally, this study offers a counterpart to Burgelman's (1994) Intel story about bottom-up flexibility-inducing processes that fuel adaptation. This study's detailed, intraorganizational view of navigating an era of ferment with competing technological options offers a high-level perspective

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of preserving flexibility and avoiding the traditional pitfalls associated with failures in organizations as well as a more granular view that suggests two core aspects of IBM's approach that facilitated renewal.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:

Appendix S1. Internal IBM documents and sources used.