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RESEARCH ARTICLE

Converting inventions into innovations in large firms: How inventors at Xerox navigated the innovation process to commercialize their ideas

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Abstract

Research Summary: How can inventors in large firms navigate their organizations' innovation processes to commercialize breakthrough inventions? Using historical case studies of three breakthrough inventions at Xerox—office workstations, personal computers, and laser printers, we illustrate how inventors navigated multiple evaluation criteria across different organizational units to attract resources toward inventions. These criteria stemmed from Xerox's first successful breakthrough invention, the 914 copier and the specific objectives of the organizational units. We highlight two approaches deployed by Xerox inventors—searching across the organization for more favorable evaluation criteria and shaping the evaluation criteria to help attract resources. While searching leveraged the heterogeneity of evaluation criteria across the different organizational units, shaping required the presence of evaluative uncertainty with respect to the appropriate criteria for evaluating breakthrough inventions.

Managerial Summary: The challenges of commercializing breakthrough inventions in large firms have been studied extensively through a lens of managerial decision-making and resource allocation. This perspective has characterized the innovation process in large firms as one in which inventors confine themselves to idea generation, leaving idea commercialization to other actors, subject to organizational inertia. We develop a complementary perspective of the innovation process in which inventors may navigate organizational inertia by going beyond idea generation to attracting resources toward commercializing their breakthrough inventions. By offering a novel account of how inventors at Xerox navigated multiple evaluation criteria to commercialize their inventions, the study sheds light on an important yet overlooked aspect of the innovation process in large firms that can facilitate the commercialization of breakthrough inventions.

KEYWORDS

commercialization, evaluation criteria, innovation process, inventors, large firms

1 | INTRODUCTION

> As I review the nature of the creative drive in the inventive scientists that have been around me, as well as in myself, I find the first event is an urge to make a significant intellectual contribution that can be tangibly embodied in a product or process.
>
> Edwin H. Land, Polaroid founder (quoted in Pace, 1991)

Strategy scholars have long recognized the challenges that large firms face in commercializing breakthrough inventions that represent new technological trajectories for the firm in existing or new markets (Ahuja, Lampert, & Tandon, 2008; Hill & Rothaermel, 2003; Wolter & Veloso, 2008).[1] An important line of inquiry within this literature has uncovered different sources of organizational inertia that hinder the commercialization of such inventions (Chesbrough, 2010; Christensen & Bower, 1996; Kapoor & Klueter, 2015; Rosenbloom, 2000; Tripsas & Gavetti, 2000). In investigating the difficulties of commercializing breakthrough inventions, scholars have highlighted the prevailing needs of firms' customers (Christensen & Bower, 1996; Rosenbloom, 2000), the fear of cannibalizing existing businesses (Henderson, 1993), financial analysts' expectations (Noda & Bower, 1996), senior managers' understanding of the firm's business model (Gilbert, 2006; Tripsas & Gavetti, 2000), the use of quantitative frameworks to evaluate investments (Baldwin & Clark, 1994; Christensen, Kaufman, & Shih, 2008), and the availability of complementary assets that may not be compatible with the focal invention (Wu, Wan, & Levinthal, 2014).

An important premise within this perspective has been that generating new ideas (invention) and converting these ideas into commercial products (innovation) are distinct aspects of the innovation process, involving different actors and processes. This split in focus meant that scholars studying invention in large firms have focused on the knowledge-based processes

[1]Once commercialized, breakthrough inventions could yield radical or disruptive innovations (Dahlin & Behrens, 2005).

affecting inventors' efficacy at generating novel ideas (e.g., Ahuja & Lampert, 2001; Fleming & Sorenson, 2004; Kapoor & Lim, 2007), while those studying innovation have focused on the managerial decision-making processes affecting the allocation of resources toward the commercialization of inventions (e.g., Christensen & Bower, 1996; Dougherty & Hardy, 1996; Tripsas & Gavetti, 2000). Accordingly, while the literature has shed light on several organizational mechanisms that contribute to the difficulties that large firms face in commercializing breakthrough inventions, it has underexplored the role of the inventors within the innovation process, beyond idea generation. The notion that inventors in large firms focus solely on idea generation fails to consider the possibility that inventors are motivated to see their ideas commercialized (e.g., Conti, Gambardella, & Novelli, 2013; Rotemberg & Saloner, 1994), and at times take an active role in commercializing their ideas (e.g., Agarwal, Gambardella, & Olson, 2016; Kannan-Narasimhan & Lawrence, 2018). This issue is especially relevant in the case of breakthrough inventions (e.g., Ahuja & Lampert, 2001), which tend to fall outside the firm's existing markets, and, absent inventors' involvement in the commercialization process,[2] might not attract organizational resources necessary for commercialization (Dougherty, 1992; Dougherty & Hardy, 1996; Gilbert, 2005).

In one example of inventor involvement in the innovation process for a breakthrough invention beyond idea generation, Christensen and Bower (1996) document Seagate engineers making 80 working prototypes of the 3.5-in. disk drives by bootlegging resources. Another study of 12 major innovations in large firms found that in 10 of the 12 cases, at least one of the idea's early proponents was actively involved for the duration of the commercialization process—a period that varied from seven to over 20 years (O'Connor & Rice, 2001). In addition, the employee entrepreneurship literature has considered inventors starting new firms to commercialize their inventions (Agarwal et al., 2016; Sørensen & Fassiotto, 2011). More recently, a number of large firms have sought to harness inventors' motivation and energy by empowering individual employees to take a more active part in the commercialization process. Bayer makes it easier for its employees to access coaching and other resources for commercializing their ideas (Birkinshaw, de Diego, Lessi, & Trill, 2018). Alcatel-Lucent set up multidisciplinary teams around individual "intrapreneurs" to help their ideas get appropriate resources (Parker & Chandrasekhar, 2015). Nokia is working to create a simulated start-up environment for its inventors (Melvin & Feinberg, 2019). Haier management reorganized the entire firm into self-directed inventor teams that bear responsibility for commercializing their ideas as well as the teams' financial performance (Hamel & Zanini, 2018).

In this article, we offer a perspective of the innovation process in large firms in which inventors play an active role in commercializing breakthrough inventions beyond idea generation. Specifically, we consider the question: how can inventors in large firms navigate the organizations' innovation processes to commercialize inventions that represent new technological trajectories for the firm?[3] To answer this question, we develop detailed historical case studies of the innovation process at Xerox during the 1970s. At the time, Xerox was a market leader known for its innovation prowess and commercialization scale. It also exhibited significant strategic foresight in terms of anticipating future technology and market trends with respect to the "office of the future," employing hundreds of engineers and scientists at Xerox Palo Alto

[2]In this article, we use the terms "commercialization process" and "innovation process" interchangeably to denote the process of converting ideas (inventions) into commercial products (innovations) in large firms.

[3]For ease of exposition, we will use the term inventor(s) as a collective noun to refer to all individual and team contributors participating in the development of an invention (Hargadon & Bechky, 2006).

Research Center (PARC), and funding their research over a prolonged period of time. The 1973 Xerox annual report described PARC's mission this way:

> Scientists and engineers at our Palo Alto, Calif., location, for example, deal in ideas for the office of the future. They are designing computer-based models for information systems—not products, not even product prototypes, but systems that will employ Xerox products years hence. Part of our research is aimed at devising total systems to handle the flow of information—from its creation to its distribution, storage, recall and reproduction either in electronic display or hard-copy form. We're no longer just a copier company as we were in the early '60s. But no matter how big we get, we'd like to think that if another Chester Carlson [inventor of xerography] walks through the door with a great idea like xerography, we'll be able to recognize it. (Xerox Corporation, 1973, p. 10)

However, despite this foresight and investments, Xerox commercialized only a handful of inventions that originated at PARC. The accounts of Xerox's failure to commercialize other PARC inventions focus on the organizational inertia stemming from its prevailing business model and inventors leaving Xerox to commercialize their inventions via employee spinoffs, many of which developed different business models (Chesbrough, 2002, 2010; Chesbrough & Rosenbloom, 2002).

What has been somewhat underexplored is the role that many of Xerox's inventors played in navigating the commercialization process within Xerox, and in some cases achieving commercialization of their inventions. To shed light on the inventors' role in the innovation process, we identified three breakthrough inventions that originated at PARC in the 1970s—office workstations, personal computers, and laser printers. Each of these inventions represented a new technological trajectory for Xerox with a broad array of potential market applications. However, while Xerox commercialized office workstations and laser printers, that was not the case for personal computers.

In exploring the differences between these inventions and the role of the inventors in the commercialization process, we observe that the resource allocation process towards the commercialization of these inventions was subject to an overarching set of evaluation criteria shared by managers across Xerox. These criteria included achieving high volume with high profit margins, requiring heavy R&D investment, and helping Xerox compete with IBM. The criteria stemmed from the company's first successful breakthrough invention, the 914 copier. Office workstations fit with all of these criteria and managers at Xerox readily allocated significant resources toward the invention's commercialization. In contrast, laser printers and personal computers did not fit with all of the criteria and encountered resistance with respect to resource allocation within the organization.

Inventors responded to this resistance by taking a more active role in the innovation process. While Xerox's experience with 914 formed an overarching set of evaluation criteria, the size, and the complexity of its organization translated into a variety of specific decision-making criteria used by managers across different organizational units (e.g., different functions, business units) with different objectives and resource constraints. Inventors deployed two different approaches for attracting resources toward the commercialization of their inventions from the organization. First, they searched for organizational units with evaluation criteria that were more favorable toward their inventions. Second, they shaped the specific evaluation criteria to favor their inventions. Through these efforts, inventors were successful in attracting resources and achieving the commercialization of laser printers, but fell short of achieving commercialization of personal computers. While success with respect to searching depended on the heterogeneity of the evaluation criteria deployed across the different organizational units in Xerox, success with respect to shaping required the presence of evaluative uncertainty with respect to the appropriate criteria for evaluating a breakthrough invention.

By offering a novel account of how inventors at Xerox navigated the set of evaluation criteria to commercialize their inventions, the study sheds new light on an important yet overlooked aspect of the innovation process. In so doing, it broadens the imagery of Xerox's innovation process from one in which inventors' role in the innovation process was confined to either internal idea generation or external commercialization via spinoffs (Chesbrough, 2002; Chesbrough & Rosenbloom, 2002), to also navigating the set of internal evaluation criteria and attracting resources toward the commercialization of their inventions. It was the latter process that helped explain Xerox's eventual commercialization of laser printers and the significant efforts expended toward the commercialization of personal computers.

2 | INVENTORS AND THE CHALLENGES OF COMMERCIALIZATION IN LARGE FIRMS

Large firms rely on innovation to sustain themselves. To do so, they charge a significant number of employees with generating new ideas (i.e., inventions) and allocate substantial resources to converting these ideas into commercial products (i.e., innovations). However, not all promising ideas reach fruition. Extant literature points to a discrepancy between inventors' expectations and their employers' achievements in commercializing breakthrough inventions. For instance, RCA's engineers saw an irony in RCA's failure to commercialize its transistor technology while at the same time licensing transistor patents to Sony, who eventually became a market leader (Henderson & Clark, 1990). Some members of the inventor teams experience frustration with firms allocating inappropriate resources to commercializing the inventions. For instance, Tripsas and Gavetti (2000) describe as "frustrated" (p. 1156) one member of Polaroid's Electronic Imaging Division who disagreed with the senior management's decision to assign the marketing of a high-end digital camera to a sales force used to targeting Walmart.

Researchers have attributed the difficulties encountered by the inventors advocating for the commercialization of their ideas to a combination of a lack of skill and scarcity of corporate resources allocated to the innovation process (O'Connor, 2008; O'Connor & Rice, 2001). Hansen and Birkinshaw (2007) cite a representative experience of an R&D manager at a large firm:

> When Stewart Davies became head of R&D at BT in 1999, the UK telecommunications group was in financial trouble. Davies reviewed operations within R&D and recalled being staggered by the inventiveness—and the frustration—of the people he met. There was no shortage of good ideas at the company, he concluded. But inadequate commercial skills and a shortage of seed money for high-risk projects made it difficult for anyone to move forward with ideas for new technologies. (p. 124)

A recurring theme in the innovation scholarship is that inventors respond to their employers' failure to allocate resources to the innovative projects by leaving the firms. Christensen (1993) described inventors leaving large firms "in frustration" at "loss or scaling back of their program" (p. 562). Rosenbloom (2000) characterized the founding of Computer Research Corporation as a result of the founders' desire to continue working on a project that their prior employer would not continue funding. Here is how Gordon Moore expressed his motivation for leaving Fairchild Semiconductor to found Intel:

> I had become increasingly frustrated with the difficulty involved in transferring new products and technology into the manufacturing organization of the company as the semiconductor division grew and became more successful. It seemed that it was much easier to get new technology picked up by groups that would spin off and start a new company than it was to transfer it to our sister operations. (Moore, 1996, p. 59)

As this quote suggests, many inventors exit large firms in response to difficulties associated with commercializing inventions. Moreover, Moore's experience in founding a successful spin-off is representative of the success attained by other inventors exiting large firms. Christensen and Bower (1996) described the founder teams of new entrants taking advantage of disruptive technology as "usually including members of the frustrated engineering teams from established firms" (p. 209).

Why do inventors struggle to attract resources to their ideas? One reason is that commercialization is a resource-intensive process and large firms generate more ideas than they can commercialize. For instance, a study at 3M found that out of every 2,000 ideas generated, 200 become formal proposals and only six emerge as commercial products (Voorhees, 1990). The abundance of ideas forces managers to make choices about how to allocate scarce resources. Existing scholarship has argued that such scarcity is evident with respect to managerial attention (Joseph & Wilson, 2018; Ocasio, 1997; Simon, 1976), knowledge and expertise (Bartlett & Ghoshal, 1993), production capacity (Burgelman, 1994; Dougherty & Cohen, 1995), as well as financial resources and staff time (Dougherty, 1992).

The relative scarcity of organizational resources vis-à-vis the availability of new ideas means that managers must deploy decision criteria to allocate resources to inventions and the decision criteria tend to favor investment in the firms' existing business lines. Accordingly, large firms struggle to commercialize breakthrough inventions because of the difficulties they incur in allocating resources to ideas that fall outside the firms' core businesses (Chesbrough, 2010; Christensen & Bower, 1996; Rosenbloom, 2000; Tripsas & Gavetti, 2000). The literature on firms' resource allocation decisions has documented a range of criteria large firms use in allocating resources to innovations. Scholars have argued that the dearth of resource allocation to breakthrough inventions is driven by the demands of firms' mainstream customers (Christensen & Bower, 1996; Rosenbloom, 2000), firms' lack of willingness to cannibalize their established businesses (Henderson, 1993), equity market analysts' expectations (Noda & Bower, 1996), senior managers' understanding of the firm's business model (Gilbert, 2006; Tripsas & Gavetti, 2000), the use of quantitative frameworks to evaluate investments (Baldwin & Clark, 1994; Christensen et al., 2008), and the availability of complementary assets that may not be compatible with the focal invention (Helfat, 1997; Teece, 1986; Wu et al., 2014).

Breakthrough inventions can play an important role in sustaining large organizations. However, organizational processes can inhibit the allocation of resources toward the commercialization of such inventions. Given the organizational challenges of resource allocation toward commercialization of breakthrough inventions and the frequent frustration of inventors with respect to the commercialization of their ideas, how can inventors navigate their organizations to attract resources to commercialize their ideas?

To answer this question, we consider the commercialization of an invention in large firms as entailing a series of resource commitments within the innovation process, involving multiple decision-makers across the organization (Noda & Bower, 1996; O'Connor & Rice, 2001). For instance, at Procter and Gamble, major product "proposals often received 40 or 50 revisions as they were exposed to the various 'layers of wisdom' in product development, sales, finance, and top management. Eventually, they reached to CEO, who would make a decision" (Herbold, 2002, p. 74). As this quote suggests, commercializing a new idea requires buy-in of both the managers of functional units and senior managers. Procter and Gamble's innovation process is representative of the processes employed by other large firms. Peters and Waterman (1982) cite a moderately technological firm in which the new product approval process involved the work of 17 committees and 223 linkages among them (pp. 17–19).

The innovation process in large firms is subject to a series of resource allocation decisions that are guided by a set of evaluation criteria. Some of the evaluation criteria are shared beliefs common to the decision-makers across the organization. These criteria can have roots in the organization's past success, its prevailing business model, as well as the background and experience of its senior managers (Benner & Tripsas, 2012; Christensen & Bower, 1996; Tripsas & Gavetti, 2000). The extent to which an invention fits these criteria makes it easier for the invention to attract resources, even for inventions that represent new technological trajectories and market opportunities for large firms. In addition, large firms' size and complexity can translate into a variety of specific decision-making criteria used by managers across different organizational units with different objectives and resource constraints (e.g., different business units and functions). Each organizational unit typically operates in its own context of shared beliefs, values, and incentives (Dearborn & Simon, 1958; Dougherty, 1992; Leonardi, 2011; Tushman, 1977). These differences can translate into a variety of evaluation criteria across the organization. Further, there can also be differences in the evaluation criteria at different levels of the organizational hierarchy such as those between top and middle managers (Burgelman, 1994, 1983; Rosenbloom, 2000; Taylor & Helfat, 2009; Tripsas & Gavetti, 2000).

In this paper, we explore how inventors might navigate the multiple evaluation criteria in seeking to attract resources to their ideas. We consider this inventor-centric view of the innovation process as a resource-attraction perspective. To illustrate the resource-attraction perspective, we develop detailed historical case studies of Xerox PARC employees' efforts to commercialize three breakthrough inventions during the 1970s—office workstations, personal computers, and laser printers. The cases provide us with a basis for reconstructing the inventors' resource-attraction process for each of the three inventions, shedding light on the different types of interactions between the inventors and the internal evaluation criteria, and the variation in the commercialization paths for the three inventions.

3 | METHODS, SOURCES, AND EMPIRICAL CONTEXT

To understand how inventors attract resources toward commercializing their inventions in a large firm, we develop three detailed historical case studies comparing and contrasting the commercialization processes of three breakthrough inventions originated at the Xerox PARC during the 1970s: office workstations, personal computers, and laser printers. Historical case study is a method well suited for documenting the nuanced patterns of causality in firms' innovation processes (e.g., Cattani, Dunbar, & Shapira, 2017; Graham & Shuldiner, 2001). We selected these inventions using theoretical sampling (Eisenhardt & Graebner, 2007; Glaser & Strauss, 1967) as a way to display variation in inventor approaches to navigating the innovation process. The nested case study design of analyzing three inventions in one firm allows us to explore this variation while holding constant the firm-level factors (Thomas, 2011).

The three inventions were breakthroughs because they represented new technological trajectories outside the core xerography trajectory for Xerox. The commercialization processes for the three inventions took place during the same timeframe in the same organizational context but entailed different types of interactions between the inventors and the internal evaluation criteria, yielding distinct commercialization paths. Figure 1 maps the timeline of the commercialization process for the three inventions.

Extant management research has offered a rich account of Xerox's efforts around generation of breakthrough inventions and the firm's challenges around commercialization of those inventions during 1980s and 1990s (Chesbrough, 2002; Chesbrough & Rosenbloom, 2002). These studies have also highlighted the importance of employee spinoffs in commercializing breakthrough inventions such as the Ethernet (3Com) and the document publishing software (Adobe). We contribute to this account by focusing on Xerox's internal innovation process and exploring the role of inventors in navigating the internal evaluation criteria and attracting resources toward the commercialization of their inventions.

In our research, we first drew upon the published historical accounts of the events of interest and then supplemented them with extensive archival research to fill in the gaps (e.g., Taylor & Helfat, 2009). In developing the three case studies, we consulted a number of books dedicated to the innovation process at Xerox PARC (Hiltzik, 1999; Smith & Alexander, 1988), the Xerox innovation process (Allison, 1976; Jacobson & Hillkirk, 1986; Owen, 2004; Pell, 1998), and senior managers' decision-making (Kearns & Nadler, 1992). We then undertook extensive archival research, consulting the original documents that included the technical specification documents and corporate memos justifying the specifications generated by the Xerox employees for the focal inventions. We consulted materials in several extant archives, including Xerox corporate archives, the Robert W. Taylor papers at the Stanford University Library Special Collections, as well as the online archives maintained by bitsavers.org and digibarn.com. A repository

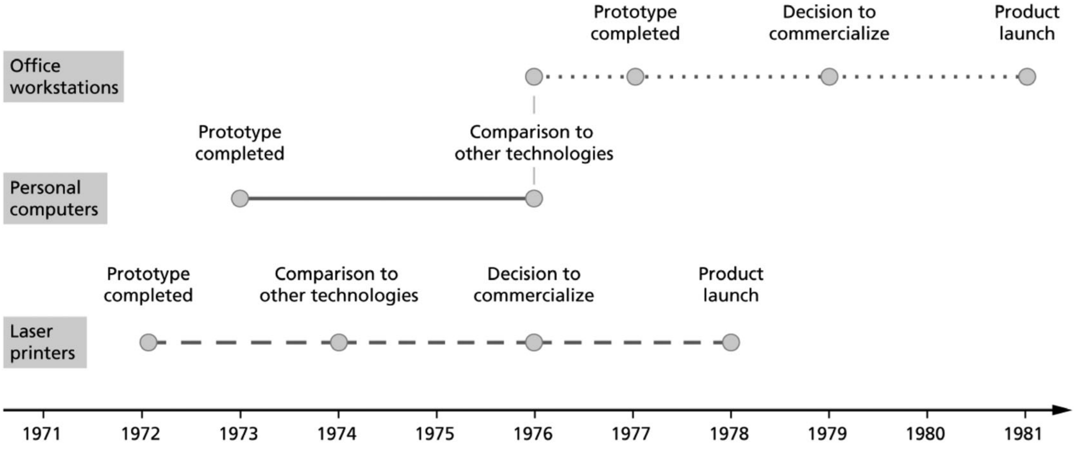

FIGURE 1 Commercialization process timeline for the three inventions

of oral histories (collected between 1988 and 2010 by the Computer History Museum) supplemented our understanding of how the inventors navigated the innovation process. Going beyond the archives, we reached out to individual inventors, their heirs, and authors of books about Xerox for help locating specific documents from the period. We matched the archival documents to contemporaneous coverage of Xerox and Xerox PARC activities in the business press and the company's annual reports.[4]

Our analysis of these sources reflects three key aspects of an historical approach: source criticism, triangulation, and hermeneutics (Kipping, Wadhwani, and Bucheli, 2014; Vinokurova, 2020). Source criticism entails the need to establish both the authenticity (time and source of production) and validity (the reliability of the informants producing the documents) of the sources. Triangulation requires drawing on multiple written sources to establish a more accurate understanding of the relevant context, overcoming the biases in the individual sources. Finally, hermeneutics necessitates interpreting the sources with an understanding of how the production of the source material fit into the historical context.

Following these guidelines, we started by carefully establishing the provenance of each document and contacting the documents' authors to resolve any ambiguities, such as acronyms, we encountered in the archival documents. We triangulated the reports about the focal events of interest across multiple sources. We then read the available materials about Xerox's history before PARC was founded and contemporary business press to understand the broader context for the Xerox innovation process. Finally, in developing the historical case studies, we iterated between the narratives emerging from the three cases to inductively derive the main features of the inventors' resource-attraction process.

In presenting our findings from the case studies, we start by providing a short background on Xerox, which is relevant to understanding the organizational context and its implications for the innovation process. We then outline the decision-making processes at Xerox as they relate to the three cases. Finally, we describe how inventors navigated the internal evaluation criteria in order to attract resources, and commercialize their inventions.

3.1 | Xerox background

In the 8 years between 1957 and 1965, Xerox's sales grew from $26 million to $475 million and its stock price went up 4,000% (Forbes, 1965a, 1965b; Haloid-Xerox Corporation, 1958). The stellar growth was driven by the copier products, and, in particular, the introduction of the 914 copier—the first copier to make copies on plain paper at the push of a button—in 1960.[5] These products resulted from a series of major R&D investments Xerox made starting in 1946, to develop xerography from an idea originated by an individual inventor—Chester Carlson. Between 1947 and 1952, Xerox (then named Haloid) invested $4.3 million in the development of xerography without realizing any profits from the technology until 1953 (Hammer, 1962).[6] By 1963, the investment transformed Xerox from a medium-size company manufacturing

[4]The online appendix provides a complete list of sources we consulted.

[5]The copiers marketed before 914 relied on specialty papers and manual application of different chemicals to produce copies the quality of which deteriorated over time.

[6]Haloid changed its name to Haloid-Xerox in 1958, the year before 914 was launched, and to Xerox in 1960 to reflect the growing share of xerographic copier products in its portfolio (Haloid-Xerox Corporation, 1958, 1960).

specialty paper for photography and photocopying with annual sales of $7 million, to a Fortune 500 behemoth. The company's earnings continued to increase until 1975.

After more than 10 years of rapid growth, Xerox senior managers were concerned that a new technology could leapfrog xerography, rendering Xerox's products obsolete (Forbes, 1965b). To keep up the growth, Xerox acquired several technology companies and in 1969, also founded a new research center in Palo Alto, California—PARC—to help the company build a path to the office of the future. In parallel with these investments, Xerox's explosive growth during the 1960s strained the firm's managerial processes.[7] To deal with the strain, Xerox senior leadership recruited managers from other large firms, including Ford, IBM, and General Motors. The managers recruited from Ford were particularly instrumental in imposing a set of rigorous financial controls on the company and changing how Xerox managed its new product development (Kearns & Nadler, 1992).[8] David Kearns, a marketing executive Xerox hired from IBM, who went on to become Xerox's CEO described the Ford executives' dedication to managing by the numbers:

> And so I'm not sure the financial measurements fully achieved their objective of telling management everything that was happening in the company. Not that the Ford Men didn't give it their best shot. One classic computer model that they came up with was christened Shazam. It was built by the finance department to calculate the impact of price changes on new product introductions. To say the least, it was unwieldy. It had something like thirty-five hundred input assumptions that were necessary in order to make a forecast. If the marketing department wished to make a price change, it had to furnish this massive list of assumptions—average copy volume, how much Instant Growth, how many customers would have cancelled their own machines if the new price did not exist and so forth—and then some seemingly precise answer would spew forth. Shazam would dictate that the new price would cause a 1.782 percent drop in sales but a 7.451 percent increase in profits—or something like that. (Kearns & Nadler, 1992, pp. 57–58)[9]

As Kearns's description suggests, detailed numerical forecasts drove the decision-making at Xerox.

Executives from Ford also introduced a phased-planning system into new product development at Xerox. In this system, each new product went through a concept phase, a feasibility phase, and a definition phase (McCamus, 1975) with each phase requiring multiple sign-offs by the different organizational units and senior managers. In 1979, product specifications required 180 signatures (Smith & Alexander, 1988). The phased-planning system, while ensuring buy-in from the entire organization, slowed down the new product development—a situation Xerox did not address until the mid-1980s[10]:

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[7]For instance, Xerox struggled with billing its customers and paying its sales people. This was because the 914 copier was a managerial as well as technological breakthrough—instead of selling, Xerox leased out the copiers and billed the customers by the copy. This approach lowered the customers' upfront costs, but required more complex billing systems than outright sales (Jacobson & Hillkirk, 1986; Kearns & Nadler, 1992).

[8]According to Kearns, Xerox hired so many managers from Ford's financial function that the Ford CFO refused to use Xerox copiers, opting instead for technologically inferior alternatives (Kearns & Nadler, 1992, p. 51).

[9]Archie McCardell, a Ford transplant who became Xerox COO, compared the use of financial reports in managing a company to the use of instruments in flying an airplane (Marsh, 1985, p. 178).

[10]The 1972 annual report warned of bureaucracy constraining individual initiative (Xerox Corporation, 1972, p. 1).

> Xerox executives now freely admit the company had strangled itself with a matrix organization. The heads of groups such as product planning, design, service, and manufacturing were based in Rochester, N.Y., but reported to separate executives at corporate headquarters in Stamford, Conn. Each group worked products through its own hierarchy; then handed them off to the next one. The groups had endless debates over features and design trade-offs and "no one had the priority for getting products out," Hicks [head of Reprographics Business Group] recalls. Disagreements often reached all the way to the president's office in Stamford. (Business Week, 1984a, p. 58)

As this quote suggests, the inventions generated by PARC had to overcome considerable barriers on their path to commercialization. Xerox was no outlier, however. Its product development process was similar to the processes in other major companies that struggled with allocating resources to breakthrough inventions (Bower, 1970; Dougherty & Hardy, 1996; Gilbert, 2005; Kapoor & Klueter, 2015; Peters & Waterman, 1982).

Our analysis of the innovation process at Xerox suggests that the innovation process entailed three stages breakthrough inventions had to pass through: (a) prototype development, (b) comparison of the prototype to alternative technologies, and (c) decision to launch the product. These stages required signoffs from multiple actors. Prototype development entailed resource-allocation decisions by the inventor's supervisor, for example, a middle manager in the R&D unit deciding how to allocate the department's funds and researchers' time across different ideas. Successful completion of a prototype could lead to further consideration of the invention for commercialization. In the second stage, a committee of middle managers across functional groups compared the prototype to other technologies available to the firm. The final stage of the commercialization process was a decision by the senior managers to launch the product.

3.2 | Xerox evaluation criteria

The evaluation criteria shared by managers across Xerox focused on assessing the invention's likelihood of replicating the success of Xerox's first breakthrough product—the 914 copier, including whether the invention helped Xerox compete with IBM. The 914 copier was Xerox's blockbuster product that resulted from a 14-year R&D program to turn xerography from an idea into a commercial product offering automated copying on plain paper.

Four aspects of the 914 experience were particularly salient to Xerox managers evaluating breakthrough inventions.[11] The first was 914's high sales volume. In 1965, Xerox's sales were 10 times higher than the firm's sales in 1959—the year before the 914 shipped, exceeding the managers' forecast of the sales doubling over the period (Business Week, 1959). Xerox manufactured more than 200,000 machines, greatly outperforming the prelaunch market size forecasts of 5,000–10,000 machines (Allison, 1976; Jacobson & Hillkirk, 1986). Second, Xerox's decision to charge by the copy translated into high profit margins enabling Xerox to benefit from the

[11]We identified these evaluation criteria for breakthrough inventions by means of an iterative inductive analysis of the primary and secondary archival sources.

growth in the copying volumes that propelled Xerox to 15 years of profitable growth.[12] Fortune (1966) called 914 "the single most profitable product ever manufactured in the United States."

Third, for many years prior to the product's launch, Xerox's investment in the development of the copier exceeded its earnings (Hammer, 1962). In retrospect, Xerox managers attributed the success of 914 to this "bet your company" level of investment (Allison, 1976). This attribution shaped Xerox managers' views of product development. The head of Xerox Business Development Group expressed these views as: "There is no way to bypass it. In order to make big money, you must spend big money" (Smith & Alexander, 1988, p. 176). This lesson, combined with the implementation of phased planning at Xerox, translated into the belief that any worthwhile technological development required the employment of hundreds of engineers (Jacobson & Hillkirk, 1986).

Finally, 914's success instilled a mindset of aggressively competing with IBM. Before commercializing the 914, Xerox executives, recognizing the small company's lack of resources, made several attempts to interest IBM in developing xerography as a commercial technology.[13] Following IBM's rejection of these attempts, in marketing their copiers Xerox executives copied IBM's business practices—leasing rather than selling the equipment (Hammer, 1962) and developing a nationwide sales and service organization (Dessauer, 1971). Executives' view of Xerox as competing with IBM drove Xerox's acquisitions and internal R&D efforts in office automation (Forbes, 1972). The acquisitions included the purchase of a mainframe manufacturer (Forbes, 1969), two printer manufacturers, and a manufacturer of computerized word processing systems (Business Week, 1976). Additionally, competing with IBM (and its investment in basic research at Yorktown Labs), in part, motivated Xerox to establish the Palo Alto Research Center (PARC) in 1969 (Hiltzik, 1999; Strassman, 2008).

These four criteria—high volume, high margin, high development costs, and making Xerox competitive with IBM—were widely shared across organizational units (Kearns & Nadler, 1992). While the managers in different organizational units deployed a variety of other criteria in pursuit of specific objectives, Xerox's experience with 914 formed an overarching set of evaluation criteria across the entire organization. Xerox executives viewed both their R&D and their M&A activities as the search for the next 914; with each innovation and acquisition prospect evaluated based on its likelihood of becoming the next blockbuster product for the firm (Smith & Alexander, 1988; Strassman, 2008). Accordingly, Xerox managers evaluated inventions that matched the four criteria, as meriting further allocation of resources toward their commercialization. Table 1 shows how each of the three inventions we examine compared to the evaluation criteria.

[12]Smith and Alexander (1988) described the relationship between Xerox's profit margins and the decision to charge by the copy: "In its first year of operation, the average 914 generated enough copies, and hence revenues, to pay for all of the manufacturing, sales, administration, and overhead costs associated with the machine. At the end of the year, of course, Xerox still owned the 914 because of the decision to lease instead of sell it. So the revenues generated by the next year's usage, typically even greater as the customer's appetite for copies expanded, were mostly profit. And the same held true for the year following that. And the next. And the next. And the next" (p. 37).

[13]In 1959, IBM turned down the opportunity to manufacture 914s under license from Xerox, basing its decision on Arthur D. Little's estimate of a limited market size of at most 5,000 machines (Jacobson & Hillkirk, 1986).

TABLE 1 Comparing the inventions to Xerox' evaluation criteria based on the 914 copier success

	914	Office workstations	Personal computers	Laser printers
Volume	High	High	High	Low
Margin	High	High	Low	High
R&D investment level	High	High	Low	Low
Helping Xerox compete with IBM	Yes	Yes	No	Yes

4 | CONVERTING INVENTIONS TO INNOVATIONS AT XEROX

4.1 | Office workstations

In October 1976, Bill Souders, executive vice-president for U.S. operations, authorized the development of a "word processing software product," in anticipation that Xerox would "install tens of thousands of these units through the early 80s" (Shultz, 1977, p. 2). The decision followed a recommendation of an interdivisional word processing taskforce. The development of the product that would become an office workstation was assigned to the Systems Development Division (SDD), originally formed in 1975 to forestall the competitive threat from IBM's attempts to develop a digital copier. The product's positioning in office automation and SDD's mandate closely matched Xerox's efforts to compete with IBM.

Between 1976 and 1978, the division conducted extensive marketing surveys that reported a very high willingness to pay for the office workstation (Hiltzik, 1999). The survey's findings supported the projections of high margins that matched the profitability of the 914 copier. SDD managers also allocated vast engineering resources to developing office workstations, thus furthering the project's resemblance to the 914 along the heavy R&D investment criterion. The project began with the engineers dedicating 30-work-years over a 2-year period to arrive at a 400-page specification of the user interface for the software (Smith et al., 1982; Winograd, 1996). By the 1981 product launch, Xerox allocated 1,119 full-time employee-months to produce 254,979 lines of code (Otto, 1981).

The managers' insistence on ambitious product specifications that matched the scale of the heavy R&D investment in the 914 copier resulted in development delays and slow performance of the workstation's hardware, which had to be redesigned to accommodate increasing software demands. In 1979, the Office Products Division committed to launching office workstations as a commercial product. After many delays, Xerox launched the product in April 1981, with the division's manager suggesting that the office workstation would be the next 914 for Xerox (Business Week, 1981).

Despite receiving some positive press, the Xerox workstation came short of market acceptance. Priced at $16,595, the workstation could not compete with the IBM PC launched 4 months later with a price tag of $1,595 (Chposky & Leonsis, 1988; Hiltzik, 1999). The IBM PC lacked the graphical user interface and other advanced functionality, but the price made it easy for customers to experiment with the machine. While Xerox's office workstation did not succeed in the marketplace, the invention fit with all four of the evaluation criteria Xerox managers used to allocate resources toward breakthrough inventions. This fit facilitated the allocation of organizational resources to the invention, resulting in a top-down new product development process that eventually led to product commercialization.

4.2 | Personal computers

When Alan Kay, a research scientist, first proposed the idea of a personal computer in a May 1972 meeting of the Computer Sciences Laboratory (CSL) at PARC, the CSL lab manager countered the proposal by arguing that the machine's size did not fit with either the CSL's research on mainframe time-sharing or the neighboring Systems Sciences Laboratory's (SSL) research on distributed minicomputers (Kay, 1993). The lab manager's resistance reflected the fact that the research projects at PARC focused on mainframe computers and, thus, aligned with Xerox's efforts to compete with IBM. In the 1970s, IBM focused on large mainframe computers and IBM executives did not consider developing a personal computer until 1980 (Chposky & Leonsis, 1988).

However, two of Kay's colleagues from CSL, Butler Lampson and Chuck Thacker, agreed to further explore this idea, as they saw it as a way to change the relationship between the computers and the users from one in which multiple users competed for access to a single machine to each user having unlimited access to a dedicated machine. When the lab manager went to the East Coast to serve on a corporate taskforce, these researchers reached out to their colleagues in the two labs (CSL and SSL) for resources to help put the initial prototype together. They were able to pool scientists' discretionary research funds, and began working on the prototype of the personal computer, which they later named Alto. Upon the manager's return, the researchers justified the project's usefulness: "If our theories about the utility of cheap, powerful personal computers are correct, we should be able to demonstrate them convincingly on Alto. If they are wrong, we can find out why" (Lampson, 1972, p. 3). By early April of 1973, the first prototype was operational. The working prototype convinced the lab manager of the merits of the project, thus addressing the first managerial objection to the project:

> We see this as an idea whose time has arrived. Technology now makes it possible to produce practical and affordable personal machines. Increasingly, we see information systems problems being solved by such machines or by assemblages of them. In Alto we have a very attractive prototype of a personal computer. (Elkind, 1974)

In the memo to Xerox's head of R&D quoted above, the CSL manager suggested that combining several different markets for PC applications would result in big enough volume to merit Xerox's investment.

While personal computers fit with the 914 market-size criterion, the executives were concerned about the product's anticipated profit margins—a concern that ultimately doomed the personal computer's commercialization prospects at Xerox. In August 1976, an interdivisional word processing taskforce rejected the Alto as the basis for Xerox word processing technology. This rejection was due to the taskforce's use of manufacturing cost as an evaluation criterion for selecting a word-processing technology. The cost served as a proxy for profit margin on the assumption that the willingness to pay for personal computers and electromechanical word processors—the technology to which the taskforce compared personal computers—was the same.

Bob Potter, Office Systems Division president, committed to promoting the electromechanical technology developed by his division, argued that the Alto manufacturing costs would exceed the $5,000–8,000 manufacturing cost of the electromechanical word processor, thus making the Alto an inferior option. He based this argument on his experience with mass manufacturing of the electromechanical word processors and his understanding of the manufacturing process that was being used to produce Alto (the first Altos cost about $15,000 to manufacture (Thacker, 1973)). To address this argument, John Ellenby, a PARC engineer who redesigned the Alto for mass production, enlisted the help of Xerox's manufacturing engineers from the product cost estimation division, a different organizational unit, to develop a detailed cost forecast showing that Alto's mass manufacturing costs could be brought down to those of the electromechanical word processors. However, the opponents of Alto successfully argued that Alto could not fully reproduce the functions of a word processor without a printer, which would add another $30,000 to the cost of the system (Smith & Alexander, 1988). The taskforce endorsed electromechanical technology over personal computers, effectively foreclosing the commercialization of the Alto at Xerox.

Alto's inventors persevered in their attempts to commercialize the product after the taskforce's rejection by seeking to enlist senior managers in overriding the taskforce's decision. In 1977, Ellenby organized a showcase of the Alto at an internal product show for the top 250 Xerox executives. In 1978, Bob Taylor, another CSL manager, put together a training session to teach Xerox's top 10 executives basic programming skills (Hiltzik, 1999). Despite one of the executives' success at locating a real production problem with the help of the software, the training failed to trigger Alto commercialization. Jack Goldman, Xerox's head of R&D, convinced senior managers to offer Altos as prototypes to external customers in the hope that Xerox executives would reconsider commercializing the product. However, placing Altos at the White House and the Senate did not translate into an authorization to commercialize the Altos (Xerox Corporation, 1978).

Frustrated by the lack of progress toward commercialization, John Ellenby sent his proposal to commercialize the Alto directly to the COO, thus bypassing several levels of Xerox's hierarchy. The COO's deputy turned down the idea in 1979 (Wenrick, 1979). In 1980, Xerox officially ended the Alto project (Kearns & Nadler, 1992). The fact that personal computers did not fit with most of the 914 evaluation criteria meant that inventors encountered significant resistance with respect to resource allocation toward the invention within the organization. The inventors' efforts at searching the organization for resources to commercialize their invention helped them to complete a prototype, but did not result in commercialization despite the many attempts to attract resources from other organizational units and the senior management.

4.3 | Laser printers

Gary Starkweather came to Xerox with a PhD in optics and joined the R&D group in Webster, New York. When he proposed the idea of the laser printer, he encountered the resistance of both his immediate supervisor and managers in other organizational units. At first, Starkweather's supervisor did not want him to work with lasers because laser research did not sufficiently contribute to improving copiers and, thus, was misaligned with the efforts to produce the next 914 (Starkweather, 1997). Starkweather dealt with his supervisor's resistance by searching the nearby labs and experimental equipment manufacturers for necessary resources he could borrow to pursue his idea after hours (Starkweather, 2010). When the supervisor continued to resist Starkweather's efforts to continue developing the laser printer prototype, Starkweather searched Xerox for a research laboratory where he could continue working with lasers. In 1970, after securing the permission from the head of Xerox R&D to transfer laboratories, Starkweather transferred from a research lab in Webster, NY, to the Optical Sciences Laboratory at PARC, which had a mandate to pursue a broad range of optics research, and saw the emergence of the laser technology as a good fit with that mandate. The transfer allowed Starkweather to collaborate with other PARC researchers and complete the prototype.

After the researchers completed the laser printer prototype, the engineering and manufacturing division resisted market-testing the prototype because the anticipated small market size for laser printers did not fit with the 914's high sales volume criterion. Specifically, in 1972, the division refused to authorize the placement of five laser printer prototypes at the Lawrence Livermore National Laboratory. The executive in charge of the division vetoed the plan because he was concerned that Xerox would lose $150,000 over the life of the contract on the servicing costs for the five printers.[14]

> O'Neill saw little point in committing Xerox to selling a machine for which there was no immediate prospect of high-volume production or marketing backup. The company would not sell Livermore a prototype copier; why sell it a prototype laser printer? (Hiltzik, 1999, p. 142)

As this quote suggests, Xerox managers had trouble authorizing market tests for products that did not match the 914 copier's large market size.

In addition to these challenges around market size, the inventors also had to secure the endorsement of the computer printing taskforce, convened in 1974 to choose which printing technology Xerox would commercialize among laser printers, cathode ray tube, and other emerging printing technologies. Gary Starkweather and Jack Goldman, Xerox's head of R&D, succeeded in steering the taskforce's evaluation criteria away from relying solely on financial metrics, such as manufacturing cost. To accomplish this, Goldman initiated an informal demonstration of laser printers for taskforce members:

> It was Monday night. I commandeered a plane… I took the planning vice president and the marketing vice president by the ear, and I said, "You two guys are coming with me. Clear your Tuesday calendars. You are coming with me to PARC tonight. We'll be back for the 8:30 meeting on Wednesday morning." We left around 7:00 p.m., got to California at 1:00, which is only 10:00 their time, and the guys at PARC, bless their souls, did a beautiful presentation showing what the laser printer could do. If you're dealing with marketing or planning people, make them kick the tires. All the charts and all the slides aren't worth a damn. (Perry & Wallich, 1985, pp. 67–68)

Goldman's account reflects his appreciation for the different evaluation criteria deployed by the different organizational units and the importance of customizing the presentation to these criteria.

The demonstration enabled the inventors to further shape the taskforce's evaluation criteria.[15] Impressed with the laser printer, members of the taskforce asked Starkweather how they should evaluate the relative merits of the competing printer technologies. This request attests to the evaluative uncertainty Xerox managers experienced in assessing the merits of laser printers as a breakthrough invention, that is, Xerox managers lacking a predetermined set of

[14]Livermore offered to pay $100,000 for each prototype (Starkweather, 2010).

[15]Seeing the laser printers in daily use at PARC helped the executives envision the role laser printers would have in the office of the future (Business Week, 1983).

criteria guiding their evaluation. The uncertainty allowed Starkweather to shape the taskforce's evaluation criteria. Specifically, he suggested asking each inventor team to print the same document and comparing the outputs from the different technologies to make a decision. More specifically, Starkweather proposed a test document that included graphics and a variety of fonts. The proposed test document leveraged the strengths of his device—a printer capable of printing any possible image rather than only the basic text that constituted computer output at the time—the target output of the technologies laser printers were evaluated against (Starkweather, 2010). In so doing, he redefined the meaning of computer printing at Xerox, thus shaping the evaluation criteria to favor laser printers.

After the taskforce endorsed laser technology, laser printer inventors continued to search for resources to help them obtain senior managers' approval for product market launch. When IBM introduced its high-speed laser printer in 1975, Xerox was close to canceling its laser printer development. The senior management's misgivings about the laser printers' projected low sales volumes not fitting with the 914 copier were further compounded by the functionality differences between laser and conventional printers. First, as a nonimpact printer, the laser printer could not make carbon copies—a feature that was typically present in the impact printers marketed at the time. Second, the printer worked with 8 ½ by 11 paper and could not handle 11 by 14 ⅞ fan paper, commonly used for computer output (Oren et al., 1980). Furthermore, the Xerox laser printer would be priced at $295,000 (Industry Week, 1977)—almost three times as much as Xerox's most expensive copier.[16] These differences between the laser printers and Xerox's copier products meant that the Xerox senior management would not green light the project without a credible market forecast (Rothkopf, 2000).

To help clear the last hurdle, the inventors enlisted the Analysis Research Group, a small staff group at PARC, to develop a novel market forecasting model to convince the Xerox senior managers to launch the product. The group was receptive to working on the laser printer project because its members saw themselves as cutting edge management scientists who took pride in publishing their work in peer-reviewed journals and saw the project as an opportunity to advance the state of the art[17]:

> The eventual agreement to proceed with the development of the forecasting system was a partnership of necessity: the 9700 [laser printer] program team needed a credible forecast for its product, and we needed a practical context for testing and extending our approach to market analysis. (Oren et al., 1980, p. 78)

Xerox launched its laser printer in 1978 (Xerox Corporation, 1978). By 1983, laser printers accounted for $2 billion of the company's $8.5 billion revenues (Business Week, 1984b), exceeding the market forecasting model's projections (Rothkopf, 1993). The laser printer remains the single most important product invented at PARC that Xerox commercialized. The inventors' success at searching for organizational units with more favorable evaluation criteria, and shaping the evaluation criteria of the task force comparing alternative printing technologies, helped attract resources toward the commercialization of laser printers.

[16]Xerox's most advanced copier, the 9200, was launched in 1973 and priced at $105,000 (McElheny, 1977).
[17]For instance, one of the model's creators independently derived logit choice modeling (Rothkopf, 2000).

4.4 | Findings summary

In all three cases, the resource allocation process toward the commercialization of inventions was subject to an overarching set of evaluation criteria used to assess an invention's likelihood of replicating the success of the 914 copier. In the case of office workstations, the invention's fit with all of the 914 evaluation criteria resulted in a process in which inventors could focus on idea generation and turn over the commercialization to the rest of the organization. This is consistent with the prevailing view of the role of the inventor within an innovating organization and how resources are allocated toward the commercialization of the invention (e.g., Burgelman, 1983; Christensen & Bower, 1996; Dougherty & Cohen, 1995). In the cases of personal computers and laser printers, however, the inventions did not fit with all of the criteria and encountered significant resistance with respect to resource allocation within the organization. The inventors responded to this resistance by taking a more active role in the innovation process to attract resources toward commercializing their inventions. In both cases, inventors addressed the managers' resistance by *searching* for other organizational units with more favorable evaluation criteria. Moreover, in the case of the laser printer, inventors went beyond searching across other organizational units to also *shaping* the evaluation criteria applied to their inventions.

The heterogeneity in the evaluation criteria applied to breakthrough inventions across the organization played an important role in enabling the success of inventors' search for resources. Both the personal computer and laser printer inventors relied on this heterogeneity in attracting resources from their informal networks in neighboring labs to help them complete the prototype. In the case of personal computers, the Computer Sciences Laboratory manager saw the invention as being at odds with the lab's mission. However, the individual scientists reporting to him and their colleagues in the neighboring Systems Sciences Laboratory saw personal computers as a way to make computing more accessible to individual users who previously had to share mainframe computing resources, and thus were more open to allocating their discretionary research funds to experimenting with personal computers. Similarly, the laser printer inventor's transfer to PARC was facilitated by the fact that the PARC Optical Sciences Laboratory had a mandate for pursuing a broad range of optics research, and saw the emergence of the laser technology as a good fit with that mandate. Further, to address the evaluation criteria for the final commercialization decision laser printer inventors searched for resources to help them put together a credible market forecast. Inventors were able to attract resources for the development of the market forecasting methodology from the Analysis Research Group because its members saw themselves as cutting edge management scientists who took pride in publishing their work in peer-reviewed journals and saw the project as an opportunity to advance the state of the art, and at the same time, help Xerox arrive at the next 914. Absent such heterogeneity in the evaluation criteria applied by the different organizational units, inventors' search for resources may not have yielded the desired outcomes.

When it came to navigating the criteria deployed by the respective taskforces to select the most promising technology, the personal computer and laser printer inventors used different approaches. The personal computer inventors took the existing evaluation criteria as given, and searched for ways to address them (e.g., enlisting the help of the manufacturing engineers from the product cost estimation division). In contrast, the laser printer inventors preemptively sought to shape the criteria applied to their invention in order to prevent the taskforce from relying solely on financial metrics. They did so by organizing a demonstration of their technology, which helped the members of the taskforce recognize the possibility that important functional characteristics of the laser printing technology were not captured by financial metrics. The inventors leveraged the evaluative uncertainty to actively shape the evaluation criteria to also include the actual printing performance of the alternative technologies with respect to different types of fonts and graphics. It is possible that the laser printer inventors' prior experience with attempting to meet the existing evaluation criteria informed their approach. The unsuccessful attempt to convince the engineering division to offer laser printers as prototypes to the Lawrence Livermore National Laboratory could have helped them recognize the difficulties entailed in fitting a breakthrough invention into an existing set of financial metrics and the need to shape the evaluation criteria to fit their invention. It is also possible that the personal computer inventors sought and failed to shape the word processing taskforce's evaluation criteria, for instance, by introducing new considerations (e.g., ease of use) into the taskforce's decision-making with respect to alternative technologies for word-processing. Such failure could have to do with an absence of evaluative uncertainty on the word processing taskforce, that is, the taskforce could have been confident in using the right set of criteria and saw little need for inventor input.

Table 2 offers a brief summary of our findings in terms of how the laser printer and personal computer inventors navigated the multiple evaluation criteria during the innovation process.

TABLE 2 Inventor approaches to navigating the evaluation criteria at Xerox

Invention	Stage	Fit with the evaluation criteria	Inventors' approach to navigating the evaluation criteria	Outcome
Personal computers	Prototype development	Inventors' immediate supervisor did not see how the personal computer idea helped Xerox compete with IBM.	Inventors searched for researchers interested in the project, putting together the prototype using funds pooled from researchers' discretionary budgets across laboratories while the supervisor was on the East Coast.	The supervisor approved the invention after seeing a working prototype.
	Comparison to other technologies	An interdivisional taskforce evaluated personal computers against electromechanical word processor technology, adopting manufacturing cost as an evaluation criterion.	The inventors enlisted the help of the product cost estimation division, but the manufacturing engineers' documentation of lower production costs for personal computers failed to sway the taskforce's decision.	The taskforce endorsed electromechanical technology for word processors, thus foreclosing the pathway to commercialization for personal computers.
		The taskforce denied personal computers a pathway to commercialization.	Inventors attempted to override the taskforce's decision by appealing to senior executives up to and including the C-suite.	The COO's office turned down the proposal to commercialize the personal computer.

TABLE 2 (Continued)

Invention	Stage	Fit with the evaluation criteria	Inventors' approach to navigating the evaluation criteria	Outcome
Laser printers	Prototype development	Immediate supervisor denied resources for creating a prototype because he did not see the project as being sufficiently related to improving copier technology.	Inventor borrowed resources from other labs and external suppliers and worked in off hours.	Supervisor insisted on the inventor ending the project.
		Supervisor gave the inventor a choice of stopping the laser project or losing his support staff.	Inventor petitioned for transfer from Webster, NY to PARC, bypassing several levels in the hierarchy to obtain approval for transfer.	Inventor transferred to Xerox PARC and completed the prototype.
		The manager of the engineering division refused to make the prototypes available to Livermore National Laboratories.	Inventors argued that using depreciated Xerox equipment as a basis for laser printers allowed Xerox to market breakthrough technology at a lower price point.	Senior manager justified his refusal to offer prototypes as avoiding servicing costs in absence of high-volume manufacturing prospects.
	Comparison to other technologies	Interdivisional taskforce evaluated laser printers against cathode ray tube (CRT) and other printing technologies.	Inventor demonstrated the printer to taskforce members from marketing and planning functions to prevent the taskforce's evaluation criteria from defaulting to financial metrics.	The product demonstration was a success.
		After the demonstration, the taskforce members asked inventor for advice on how to evaluate competing technologies.	Inventor suggested judging the competing technologies by their efficacy at printing a document containing different fonts and graphics.	Inventor's suggestion shaped the evaluation criteria to favor laser printers.
	Decision to commercialize	Xerox senior managers gave the inventors 1 year to come up with a credible market forecast.	The inventors enlisted a functional group at PARC to develop a new forecasting methodology.	Xerox launched laser printers as a commercial product.

5 | DISCUSSION

The evidence from Xerox PARC builds on and extends the existing literature's understanding of the inventors' role in the innovation process (Dougherty & Hardy, 1996; Dougherty & Heller, 1994; Kannan-Narasimhan & Lawrence, 2018; Leonardi, 2011; O'Connor & Rice, 2001; Taylor, 2010). Our findings point to inventors in large firms playing an important role in the commercialization of breakthrough inventions that is broader than that generally portrayed in the existing literature (e.g., Ahuja & Lampert, 2001; Henderson & Clark, 1990; Kapoor & Lim, 2007). Specifically, we put forward an inventor-centric view of the innovation process in which inventors take an active role in attracting resources to their ideas within a large firm.

The cases of three breakthrough inventions at Xerox during the 1970s—office workstations, personal computers, and laser printers—present us with valuable evidence of how inventors navigated the innovation process to attract resources toward commercializing their ideas. The process of allocating resources toward the commercialization of these inventions was subject to an overarching set of evaluation criteria that stemmed from the company's first successful breakthrough invention, the 914 copier and included achieving high volume with high profit margins, requiring heavy R&D investment, and helping Xerox compete with IBM. In the case of the office workstation, the invention fit with all of the criteria, and managers at Xerox readily allocated significant resources toward the invention's commercialization. In contrast, laser printers and personal computers did not fit with all of the criteria and encountered resistance with respect to resource allocation within the organization. Inventors responded to this resistance by taking a more active role in the innovation process by navigating multiple evaluation criteria across the different organizational units. Specifically, they deployed two different approaches for attracting resources toward the commercialization of their breakthrough inventions—searching for organizational units with favorable evaluation criteria and shaping the criteria applied to their inventions.

These findings contribute to the literature stream that has shed light on the challenges that large firms face in commercializing breakthrough inventions (e.g., Christensen & Rosenbloom, 1995; Gilbert, 2005; Hill & Rothaermel, 2003; Kapoor & Klueter, 2015; Tripsas & Gavetti, 2000). Scholars have offered several explanations with respect to cognition, resource dependencies, and routines as impacting managerial decision-making and resource allocation toward the commercialization of such inventions. In so doing, extant literature has characterized the innovation process as one in which inventors generate ideas and other actors manage the commercialization process, subject to organizational inertia. Our examination of Xerox helps advance a complementary perspective in which inventors may navigate organizational inertia by going beyond idea generation to attracting resources toward commercializing their breakthrough inventions. Specifically, this perspective highlights that decisions to allocate resources toward the commercialization of an invention may be guided by an overarching set of criteria that is shared across the organization and several additional criteria that are specific to the different organizational units that support the innovation process.

Confining the role of the inventor in the innovation process to idea generation is particularly problematic for breakthrough inventions because these inventions are likely to encounter resistance with respect to resource allocation, and yet inventors are motivated not only to generate novel ideas but also to see their inventions commercialized (Conti et al., 2013; Rotemberg & Saloner, 1994). The somewhat narrow view of the role that the inventor plays in the innovation process is also at odds with the efforts of leading companies like Bayer, Haier, and Nokia to enable inventors to actively participate in the innovation process beyond idea generation

(Birkinshaw et al., 2018; Hamel & Zanini, 2018; Melvin & Feinberg, 2019). By offering an inventor-centric resource attraction perspective, we illustrate how inventors can deploy two different approaches—searching and shaping—to navigate the multiple evaluation criteria across the organization and enable the conversion of breakthrough inventions into innovations. Such a perspective also helps to create an important bridge between studies of invention, focusing on inventors and the generation of ideas (e.g., Ahuja & Lampert, 2001; Fleming & Sorenson, 2004; Kapoor & Lim, 2007), and those of innovation, focusing on the organizational processes with respect to commercialization of inventions (e.g., Christensen & Bower, 1996; Dougherty & Hardy, 1996; Tripsas & Gavetti, 2000).

The finding that managers at Xerox were more willing to allocate resources to inventions that fit with all of the overarching 914 criteria (e.g., office workstations) than those that did not fit (e.g., personal computers, laser printers) is consistent with the perspective of organizational inertia in large firms (e.g., Christensen & Bower, 1996; Tripsas & Gavetti, 2000). However, the cases of laser printer and personal computer inventions suggest that while organizational inertia can hinder the commercialization of breakthrough inventions, inventors can still attract resources toward the commercialization of their inventions by searching for organizational units with more favorable evaluation criteria and shaping the evaluation criteria to favor their inventions at different stages of the innovation process.

The innovation process at Xerox, like most large firms, unfolded in multiple stages from prototype creation, through evaluation of alternative technologies, to the final commercialization decision, entailing a series of resource commitments involving multiple decision-makers across the organization (Burgelman, 1983, 1994; Dougherty, 1992; Leonardi, 2011; Taylor & Helfat, 2009). These decision-makers from different organizational units applied different evaluation criteria in deciding whether to allocate resources to an idea. These evaluation criteria could reflect specific objectives or functions of a given unit (e.g., Optical Sciences Laboratory, product cost estimation division) or they could reflect the specific task within the innovation process (e.g., compare alternative technologies, generate credible market forecast). Further, for breakthrough inventions, decision-makers may be uncertain about the appropriate evaluation criteria, giving inventors the opportunity to shape the criteria to favor their inventions (e.g., printing performance with respect to different fonts and graphics in evaluating the alternative printing technologies by the taskforce, in addition to considering financial metrics).

The notion of evaluative uncertainty has been discussed in entrepreneurial settings where aspiring entrepreneurs attempt to secure funding for the commercialization of their inventions from venture capitalists (Matusik, George, & Heeley, 2008), business angels (e.g., Parhankangas & Ehrlich, 2014), and university technology transfer offices (e.g., Kim, Kotha, Fourné, & Coussement, 2019). These funders face evaluative uncertainty with respect to the reliability of the invention's technology, potential market size, and the likelihood of customer acceptance. In the presence of such evaluative uncertainty, the funders rely on idiosyncratic heuristic-based evaluation criteria for their decisions, and individual entrepreneurs have little influence over these evaluation criteria. In contrast, our observations from Xerox illustrate a different mechanism with respect to evaluative uncertainty—namely, inventors in large firms can help decision-makers recognize the presence of evaluative uncertainty and in so doing, shape the evaluation criteria to favor their inventions. Decision-makers in large firms who do not recognize this uncertainty may proceed applying traditional evaluation criteria, such as financial metrics as was the case with the word processing taskforce that evaluated personal computers. However, laser printer inventors' demonstration of their technology helped the printing taskforce members recognize the possibility of important functional characteristics of the technology not being captured by financial metrics. The taskforce members' recognition of the evaluative uncertainty thus created an opportunity for the inventors to shape the taskforce's evaluation criteria. Future research could build on our findings and advance our understanding of the antecedents and consequences of evaluative uncertainty in large firms. For instance, future research could consider the interplay between evaluative uncertainty and the cognitive and political processes within large firms (e.g., Kaplan, 2008; Taylor, 2010).

The study also contributes to the strategy literature on dynamic capabilities, which are critical to firms' sustaining their leadership during periods of industry change. This literature has highlighted the important role of sensing, seizing, and reconfiguring as a means for firms to recognize the emerging opportunities and threats, and to allocate resources to take advantage of those opportunities (Helfat & Peteraf, 2015; Teece, 2007). In so doing, the literature has offered a top-down managerial perspective of the Schumpeterian innovation process. We suggest that an alternative bottom-up inventor-centric perspective that involves both searching and shaping of organizational evaluation criteria to attract resources can also enable a Schumpeterian innovation process, and can allow a firm to sustain its leadership by commercializing breakthrough inventions. Such a perspective is also consistent with the notion that a resource environment is not necessarily exogenous but that actors can actively shape such environments (Gavetti, Helfat, & Marengo, 2017; Vinokurova, 2019).

As a historical case study of one large firm at a given point in time, our research is subject to significant limitations, which offer opportunities for future research. For example, it is possible that the innovation process at Xerox in the 1970s may differ from the innovation processes of other large firms, and that the inventor-centric perspective that we offer might not be generalizable. We note that our observations with respect to how Xerox's success with the 914 printer shaped its overarching set of criteria to evaluate breakthrough inventions are consistent with accounts of NCR (Rosenbloom, 2000; Taylor & Helfat, 2009), Polaroid (Tripsas & Gavetti, 2000), Kodak (Wu et al., 2014) and several other large firms (O'Connor & Rice, 2001). Future research could explore in greater depth how evaluation criteria in large firms come about and how they get applied across the different organizational units that support the innovation process. Strategy scholars could also build on our findings and explore the implications of the inventor-centric resource attraction perspective for firm performance.

6 | CONCLUSION

This article describes the inventor-centric resource attraction process in a large firm using three historical case studies of breakthrough inventions at Xerox PARC during the 1970s. Xerox funded the PARC research laboratory to develop the office of the future. In reflecting on the Xerox experience, it is worth remembering that at the time of PARC's founding, Xerox was synonymous with exponential growth driven by technological innovation. Xerox credited Chester Carlson, the inventor of xerography with its success, and challenged PARC scientists to help Xerox identify the next breakthrough. The talented scientists and engineers recruited to Xerox PARC rose to the challenge by generating breakthrough inventions that continue to define today's information technology landscape. While scholars have generally considered Xerox as a once-successful industry leader succumbing to forces of organizational inertia, our account sheds light on a somewhat different side of the innovation process at Xerox, one that is rooted in inventors of breakthrough inventions navigating the organization to attract resources toward the commercialization of their inventions. Our study of the process by which inventors searched for organizational units with evaluation criteria that were more favorable toward their inventions and shaped the evaluation criteria to favor their inventions offers a novel account of how inventors help large firms convert breakthrough inventions into innovations.

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SUPPORTING INFORMATION

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