INCUMBENT ADAPTATION TO TECHNOLOGICAL CHANGE:
THE PAST, PRESENT, AND FUTURE OF RESEARCH ON
HETEROGENEOUS INCUMBENT RESPONSE

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Schumpeter famously popularized “creative destruction” as the process whereby new entrants replaced existing firms. In most cases, however, some incumbent firms survive and even thrive across technological discontinuities. Moving beyond incumbent-entrant dynamics, organizations and innovation research has begun to explore incumbent heterogeneity in response to technological change—why some incumbents do well and adapt, whereas others struggle. As a phenomenon-driven research area, scholars with different theoretical perspectives have brought their own lenses to bear, but these perspectives have evolved independently. The result is a research stream with a scattered collection of detailed, within-industry perspectives on the phenomenon without a clear ability to link different mechanisms or articulate boundary conditions. This article brings these relevant literatures together to paint a more holistic picture of incumbent adaptation to technological change. To improve generalizability and begin building a more general, cross-industry theory, we emphasize recognizing specific nuances of different technological changes and how they fit with the existing capabilities, knowledge, position, and cognition of incumbent firms to understand which incumbents are swept away in the wave of creative destruction and which may survive.

INTRODUCTION

Classic work on radical innovation (Tushman & Anderson, 1986) has typically focused on the punch line inspired by Schumpeter (1934) that incumbent firms are doomed by radical technological change. Numerous studies in this vein focused on the competition between incumbent firms seeking to adapt to a new technology and entrant firms seeking to displace the incumbents. But even studies that proclaimed the doom of incumbents often pointed to heterogeneity in incumbent adaptive response. For example, whereas the core message of Christensen and Bower’s (1996) study of the disk drive industry bodes poorly for incumbents, the authors offer a deep discussion of specific firms that successfully adapted. Such stories are emblematic of many recent studies on incumbents and technological change—the existence and origins of heterogeneity among incumbents in their adaptation to technological discontinuity. Thus, the core question has shifted from “Why do incumbents fail?” to an exploration of why some incumbents adapt and survive, whereas others are inert and fail. In this article, we focus on this latter stream of research and offer, to our knowledge, a first review of the literature on the differential ability among incumbents in adapting to technological change.

Although this research significantly advances our knowledge of the dynamics of technological change and incumbent adaptation, we believe there are three problems with the state of the literature that make it difficult to obtain a holistic view. First, some studies seek to explain adaptation, or lack thereof, by focusing only on the type of technological change (e.g., classic studies on incumbents and entrants), some by focusing only on the capabilities of the firm (e.g., the dynamic capabilities literature), and some by focusing largely on the role of external actors such as suppliers and equity analysts, without providing a way to fully explore all aspects of the incumbent adaptation process. This has resulted in important
gaps in our knowledge that have not adequately been explored and underspecified theoretical models that do not adequately explore important interdependencies among multiple factors. It makes sense, for example, that key organizational characteristics facilitating adaptation in the face of one change may not be as helpful during a different type of change. Second, most studies use the term “technological change” quite loosely. For instance, “technological change” has been used to refer to the shift from analog (film based) to digital photography (Benner, 2010; Tripsas & Gavetti, 2000), the shift from copper line to fiber-optic products in communications technology (Eggers & Kaplan, 2009; Kaplan, 2008a), and shifts among different generations of hard disk drives (Christensen & Bower, 1996; King & Tucci, 2002). Although these changes all fall under the broad definition of technological change, the nature of each shift is quite different and the descriptions of each change are not offered in such a way as to facilitate comparisons. Third, because of this lack of clarity on the specific nature of the underlying technological change and the fact that most studies focus on a single industry with a single technological change, it is unclear which of the findings from one context are likely to hold in another industry with a different type of technological discontinuity. In fact, many studies almost appear to conflict, with one suggesting that a given factor facilitates adaptation whereas another suggests that the same factor impedes adaptation. This phenomenon-driven empirical work essentially offers suggestions of what may happen without a clear path forward to understand the generalizability and conditionality of the findings.

Despite these limitations in our current understanding of the phenomenon, the tone of much of the existing work comes across as searching for a single definitive answer—a silver bullet—to the problem of incumbent adaptation. Many studies offer antecedents examined in a single-industry–single-technological-change context as if they can be assumed to be stable predictors of successful adaptation in other contexts. The dynamic capabilities literature goes one step further to argue that there exists a stable set of capabilities that enable incumbents to adapt to (implicitly) any kind of technological change across all industries. Although simple answers have their appeal, we believe that such pursuit for a panacea explaining incumbent adaptation to technological change is similar to chasing Ahab’s white whale: it is an obsession that is unlikely to be fulfilled.

Various literature sections in individual empirical studies have reviewed pieces of the literature on incumbent heterogeneity in response to technological change (see Chesbrough (2015) for a review of 16 empirical studies on the topic) and multiple articles have reviewed the burgeoning literature on dynamic capabilities (Di Stefano, Peteraf, & Verona, 2010), but none has sought to integrate all aspects of this phenomenon-driven research domain. Given that this literature has not really been subjected to a full review, the goals of the present article are to offer both a review of the state of the literature on heterogeneity in incumbent response to technological change (i.e., why some incumbents survive or fail in the face of change) and provide a roadmap for addressing the challenges identified earlier.

We seek to achieve these goals using two new frameworks that help unify the existing literature. First, we outline a model of the barriers to adaptation and the processes by which firms successfully adapt. Intuitively, for an incumbent firm to successfully adapt to a given technological change, it must find the means to possess both (1) the necessary new technological knowledge and (2) the complementary assets and other means to commercialize the new technology. When the firm does not possess ex ante either of these two resources, it needs to acquire or access them externally. To frame the existing research, we suggest that important internal and external barriers may hinder an incumbent from externally accessing the two necessary components of adaptation to technological change. Furthermore, there may also be additional barriers within a firm that deter the firm from successfully adapting to a technological change even when it possesses both the necessary knowledge and the means to commercialize the new technology. We argue that the antecedents to adaptation identified by existing work determine the permeability of different barriers and affect the underlying process of circumventing these barriers for incumbents. Classifying antecedents to adaptation using this model reveals understudied antecedents to adaptation as well as potential interdependencies among the antecedents that have not yet been identified by researchers.

Second, we offer a typology for comparing different technological changes, which presents the potential to dramatically enhance discussions of generalizability across specific studies (existing and future). Our typology is derived inductively from the contexts and findings from the studies reviewed in the first section. We believe that existing categorizations of technological changes are too crude to
account for the different nature of the changes and to allow for cross-context comparisons (Ansari & Krop, 2012; Durand, 1992). We propose four key dimensions for any technological change—the effect on core knowledge, the effect on complementary assets, the effect on the external ecosystem (e.g., suppliers, buyers, stakeholders), and the nature of uncertainty in the era of fermentation. We demonstrate the use of this model in categorizing technological changes studied by existing empirical work. This model offers a coherent and consistent typology to categorize any given technological change in a way that facilitates cross-context comparisons, but that relies on authors to adequately describe the details of the technological change covered in any given study. Our approach emphasizes the importance of the fit between the nature of a given technological change and the many antecedents that may affect adaptation.

We also offer provocative questions (e.g., do antecedents of adaptation help incumbents identify the changes that will revolutionize their industry or simply lead to adaptation to any change, beneficial or not?) that future research should explore in more detail. The ultimate goal is to illustrate that chasing the white whale of a single, simple answer that explains all incumbent adaptation is likely to be a futile endeavor. We instead hope to move toward building a coherent knowledge base that helps us to understand when and why specific incumbents may or may not survive a given technological change.

Outline and Boundary of the Review

To provide a roadmap to this article, Section 2 outlines our barrier model of the impediments to incumbent adaptation, as well as a four-part process by which firms can overcome these barriers. Section 3 provides the detailed review of existing research that forms the basis of our barrier model. Section 4 identifies important missed opportunities and gaps in our knowledge across these studies. Section 5 provides details on our typology of technological change and why such a model is important to facilitate comparisons across studies. Section 6 provides concluding thoughts.

We place four boundary conditions around the scope of the present article. First, we focus only on technological change, which presents a unique class of challenges for incumbent firms by requiring a shift or expansion in the firm’s core, production-level knowledge (Teece, 1986). We exclude environmental changes based on shifts in competition, customer preferences, legal structure, or regulation that do not also come with a change to underlying core knowledge. Second, we define technology broadly, following the typical economic definition of technology as the ability to convert inputs (labor, capital) into outputs. Technological change in turn would be “any change in the application of information to the production process in such a way as to increase efficiency, resulting either in the production of a given output with fewer resources (i.e., lower costs) or the production of better or new products” (Mokyr, 1990: 6). Third, we focus on heterogeneity in incumbent response to technological change, not on the incumbent-entrant dynamic nor on technological innovation more generally (see reviews by Ahuja, Lampert, and Tandon (2008) and Cohen (2010)). We approach the question of incumbent heterogeneity as a phenomenon-driven topic and review all work with any theoretical perspective that studies this phenomenon. Fourth, we review works on exogenous technological changes, as opposed to studies on technological innovations initiated by incumbents (Banbury & Mitchell, 1995; Chandy & Tellis, 2000). Nevertheless, we acknowledge the importance of a growing literature on the idea of exaptation, which refers to innovations that end up serving a different purpose than what was initially intended (Garud, Gehman, & Guiliani, 2016).

A BARRIER MODEL OF INCUMBENT ADAPTATION

Many researchers have explored the phenomenon of technological change and incumbent adaptation, and one of the primary objectives of this article is to catalog and review these studies to document and understand the current foundation of our knowledge. However, most studies focus on one specific mechanism, leading to numerous antecedents to adaptation that quickly become an endless list of different factors. Making these various studies more useful for future research requires a theoretical foundation that identifies and explores linkages across studies. To facilitate our discussion of specific antecedents allowing (or inhibiting) incumbent

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2 This broad definition of technology and technological change is not meant to solve the loose usage of the terms. We attempt to address this problem by unpacking the three proposed components of any given technological change using our categorization model of technological change. We adopt this broad definition of technological change only to be comprehensive in our review of the literature.
firms to adapt to (exogenous) technological change, we offer a framework identifying different categories of challenges to adaptation and how they can be overcome. Although our approach integrates important high-level aspects of dynamic capabilities theory (Teece, 2007), we view adaptation primarily through a resource-based view (RBV) lens as successful adaptation entails assembling a bundle of technological and complementary resources that facilitate the development and commercialization of a new technology. This bundle of resources can be commercialized as a product or service and then sold to a set of external customers or transferred within a vertically integrated firm.

Understanding why a firm might need to assemble a new bundle of resources, however, requires a more dynamic view of resource value than is typically involved in most RBV research (Priem & Butler, 2001)—specifically considering that the value of a given resource may decline over time. The RBV implicitly assumes changes in resource value (e.g., the advice to buy low and sell high), but comparatively little research has explored resource dynamics beyond how imitability leads to decreased rarity (Peteraf, 1993) and how existing resources are rebundled and redeployed to meet new opportunities (Sirmon, Hitt, & Ireland, 2007). This comparatively static view of the RBV has been one of the criticisms of the theory (Priem & Butler, 2001). Helfat and Peteraf (2003) discuss the dynamics of capabilities that assumes a decrease in the value created by capabilities that need to be discarded, but the logic and relevance of a change in the value of strategic resources—and how this relates to the phenomenon of technological change—has not been adequately discussed in the literature.

Assume that a firm possesses a product comprised of technological and complementary resources. If an exogenous technological change decreases the value of some or all of the technological resources in the bundle, the firm will need to replace the obsolete technological resources with new resources or to create entirely new bundles of technological and complementary resources. A new technology, by definition, involves core knowledge (Teece, 1986) that is different from the core knowledge associated with the existing technology that is being replaced. The differences may be minor or more significant (one size disk drive versus another or traditional versus biotech drug development processes) but for incumbent firms to adapt, they must possess or be able to acquire the necessary new knowledge about the innovation. But firms need more than just technological resources to succeed and appropriate rents from a new technology. Possessing assets such as well-developed distribution channel can help incumbents to generate profit using a new technology (Tripsas, 1997a), but certain technological changes may destroy the value of some of these assets or necessitate the creation of new assets to facilitate commercialization. There are many potential pathways available to the firm to access new resources—they may already exist within the firm by being deployed in different resource bundles, they may be created through internal development (either with existing human capital or through the acquisition of new human capital), or they may be acquired externally through acquisition or partnership. Thus, adaptation to technological change becomes about processes of acquiring and organizing technological and complementary resources.

If adaptation is about acquiring new resources, we argue that an understanding of the factors that facilitate adaptation can be obtained by understanding the barriers that prevent some firms from acquiring and deploying new technological and complementary resources in response to technological change. Adaptation is not instant, so what sorts of frictions emerge in this process that prevent all firms from seamlessly adapting to the new technological regime. We refer to these frictions as barriers in the sense that they impede the flow of technological (and complementary) resources both from outside the firm to inside and within the firm’s boundaries. Consider the challenge in Figure 1—the firm possessed a successful product comprised of technological ($T_1$ and $T_2$) and complementary ($C_1$ and $C_2$) resources. But technological change has devalued the two technological resources, requiring their replacement with new technologies $T_3$ and $T_5$. Even though $T_3$ is already within the firm, there may be frictions around reconfiguration that prevent the firm from integrating $T_3$ into the redesigned product. $T_5$, meanwhile, is beyond the firm’s control, so it must be acquired, assimilated, and reconfigured into the product. This suggests multiple potential barriers to frictionless adaptation, as articulated by the process laid out in Figure 2. These barriers take many forms—they may be economic, technological, organizational, cognitive, etc.—meaning that the enabling mechanisms that heterogeneously allow some

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3. Hereafter, when we refer to technological change, we are referring to exogenous technological change from the perspective of an incumbent firm, unless specified otherwise.
firms to overcome these barriers may take many forms, as well. This means that, whereas the underlying model of resource value, resource acquisition, and resource reconfiguration is grounded in the RBV, the specific factors discussed across existing research are inherently drawn from multiple theoretical perspectives.

Figure 1 identifies three barriers that may exist to organizational attempts to obtain and organize both knowledge and commercialization ability. First, the firm may have the opportunity to acquire new knowledge or resources through external markets for technology (Arora, Fosfuri, & Gambardella, 2004), hiring new employees (Argote & Ingram, 2000), or allying with a partner with downstream resources (Colombo, Grilli, & Piva, 2006). But the firm may be discouraged from acquiring new knowledge or resources through an external barrier erected by stakeholders that limits organizational adaptation or because the requisite resources are scarce in the external environment and potentially controlled by competitors. One example of the former type of barrier would be analysts deterring an incumbent from investing in new technologies that are outside the domain of its core competencies (Benner & Ranganathan, 2012). Because these stakeholders possess key resources and the uncertainty of the technological environment allows for differing interpretations of the same opportunity, such external barriers may create inertia despite the firm’s best efforts. We label these as barriers to the acquisition of relevant resources.

Second, firms may have access to necessary resources but be unable to successfully integrate the new resources into the organization because internal barriers make it difficult to use those resources. A classic example is the “not invented here” (NIH) syndrome (Katz & Allen, 1982) that leads some incumbents to shun acquiring the core knowledge associated with a new technology. These integrations include absorptive capacity or the “ability to recognize the value of new information, assimilate it, and apply it” (Cohen & Levinthal, 1990: 128). In fact, internal R&D efforts are complementary to external knowledge acquisition (Cassiman & Veugelers, 2006). We consider internal barriers that prevent firms from successfully integrating new knowledge as barriers to the assimilation of new resources.

Third, additional internal barriers may prevent an incumbent from adapting even when it possesses both knowledge and resources. Adaptation is not only a process of resource acquisition and assimilation but also the reconfiguration and organization of those resources to pursue a new opportunity (Karim & Mitchell, 2000; Lavie, 2006; Sirmon, Hitt, Ireland, & Gilbert 2011). In the disk drive industry, drive manufacturers possessed both relevant knowledge and strong brands but lacked the incentive to rework their operations to adopt a new generation of smaller disk drives because existing customers did not value the new technology (Christensen & Bower, 1996). Similarly, Polaroid possessed excellent digital photography knowledge and had relevant complementary assets but could not overcome internal resistance to a new business model that would reorganize the firm’s operations.

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**FIGURE 1**
Barrier Model of Incumbent Adaptation to Technological Change

**FIGURE 2**
Adaptation Process for Incumbent Firms
Thus, the possession of knowledge and means of commercialization does not guarantee successful adaptation as firms face the third type of barrier—a barrier to reconfiguration. In sum, we propose three types of barriers of adaptation: (1) external barriers that hinder external acquisition of new knowledge and complementary resources, (2) internal barriers that hinder assimilation, and (3) internal barriers that hinder reconfiguration and integration. Overcoming these barriers is central to incumbent adaptation.

These three barriers make an initial, implicit assumption—that the firm does not already possess the core or complementary resources to successfully adapt. In addition to the reality that most changes do not devalue all existing resources and knowledge (Tripsas, 1997a), firms may ex ante possess the relevant resources for the new technological environment through processes typically discussed as exaptation. Exaptation is a “discontinuous evolutionary process expressed by functional change of a biological trait which may open a new evolutionary trajectory” (Andriani & Cattani, 2016: 116). Whereas adaptation is shaped by natural selection for its current use, exaptation is a process that leads to a novel usage of an existing trait (Gould & Vrba, 1982). In the context of technological change, exaptation refers to innovations that ultimately serve a purpose different than their intended function at the time of inception (Garud et al., 2016). The realization, for example, that the manufacturing process behind flat panel displays is inherently similar to that of semiconductors means that television firms that also had a semiconductor division already possessed some of the requisite core knowledge to survive in the flat panel display industry, simply by redeploying semiconductor manufacturing expertise (Eggers, 2014). This suggests that a new perspective on the use of a given strategic resource may be one source of technological exaptation (Felín, Kauffman, Mastrogiorgio, & Mastrogiorgio 2016). Corning’s invention and development of fiber optics technology is an instance of innovation in which a firm redeployed its existing technological knowledge in a different domain (Cattani, 2006). Although this is an instance of an incumbent introducing a technological innovation (i.e., endogenous change), it is equally plausible that incumbent firms may adapt to an exogenous technological change by leveraging its existing technological knowledge in a different manner that is compatible with the new technology in question. Firms often possess knowledge that is beyond what is necessary for what they produce (Brusoni, Prencipe, & Pavitt, 2001), and this may be a source of technological exaptation that may enable incumbents to successfully adapt to a technological innovation. Thus, before considering processes around acquisition and assimilation of new knowledge (reconfiguration would still be required), it is worth considering the firm’s possession of relevant knowledge initially.

We use the barrier model in Figure 1 and the four stages of overcoming those barriers shown in Figure 2—possession, acquisition, assimilation, and reconfiguration—to provide a framework through which to view existing research on incumbent adaptation and understand how different factors affect the strength and permeability of the barriers. The framework has clear analogies to the dynamic capabilities framework of sensing, seizing, and reconfiguring (Teece, 2007) but takes a more resource-focused approach to seizing and reconfiguring that recognizes that even more than specific capabilities that enable firms to be more adaptable, dynamic capabilities may manifest more as the absence of barriers (or frictions) to adaptation. Categorizing the existing work according to our four stages allows us to paint a holistic picture of what we know (and do not know) about the phenomenon of technological change and incumbent adaptation. Each antecedent to adaptation that we discuss in detail below contributes to at least one of the four stages in the adaptation process, and one antecedent can affect more than one stage. For instance, an incumbent firm’s experience can increase its ability to assimilate the knowledge for the new technology (Eggers, 2012a; Klepper & Simons, 2000) (i.e., weaken internal barriers that may hinder assimilation of knowledge), and experience can also increase a firm’s ability to commercialize an innovation (Eggers, 2012b; King & Tucci, 2002) (i.e., weaken internal barriers that may hinder assimilation of means of commercialization). Possession of complementary assets, on the other hand, not only increases an incumbent’s ability to commercialize a new technology (Teece, 1986; Tripsas, 1997a), but it also incents an incumbent to adopt the innovation in the first place (Helfat & Lieberman, 2002; Mitchell, 1989) (i.e., weaken internal barriers that may hinder reconfiguration through the integration of knowledge and means of commercialization). Table 1 summarizes the categorization of antecedents that we detail below, provides a sense of some representative work around each antecedent, and identifies what existing work to date has said about that antecedent’s effect on each stage of the adaptation process.
<table>
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<tr>
<th>Antecedents</th>
<th>Representative Work</th>
<th>Possession</th>
<th>Acquisition</th>
<th>Assimilation</th>
<th>Reconfiguration</th>
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</thead>
<tbody>
<tr>
<td>Firm size</td>
<td>Agarwal and Audretsch (2001), Banbury and Mitchell (1995), McKendrick and Wade (2010)</td>
<td>Larger firms are more likely to possess relevant resources <em>ex ante</em></td>
<td>Larger firms are better able to acquire new knowledge</td>
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<tr>
<td>Firm experience</td>
<td>Cattani (2005), Eggers (2012a, 2012b), Franco et al. (2009), King and Tucci (2002), Klepper and Simons (2000), Sosa (2009, 2013)</td>
<td>Firm experience is likely to increase a firm’s excess knowledge (i.e., knowing more than it produces)</td>
<td>Firm experience increases a firm’s ability to acquire new knowledge and new complementary assets</td>
<td>Firm experience increases a firm’s ability to assimilate new knowledge and incorporate new complementary assets</td>
<td>Adaptive experience builds a firm’s reconfiguration capabilities</td>
</tr>
<tr>
<td>Complementary assets</td>
<td>Helfat and Lieberman (2002), Mitchell (1989), Rothenberg and King (2005), Teece (1986), Tripsas (1997a)</td>
<td>Possession of complementary assets strengthens ability to commercialize</td>
<td></td>
<td>Possession of complementary assets can be leveraged to acquire knowledge externally</td>
<td>Complementary assets strengthen a firm’s ability to assimilate new knowledge</td>
</tr>
<tr>
<td>Commitments and cannibalization</td>
<td>Benner (2009), Benner and Tushman (2002), Chandy and Tellis (1998), Christensen and Bowker (1996), Gilbert (2000), Leonard-Barton (1992), Sull et al. (1997)</td>
<td>Strong commitments make it less likely that a firm possesses knowledge or complementary assets relevant for a new technology</td>
<td>Strong commitments to existing technology and lower willingness to cannibalize existing product decreases a firm’s incentive to acquire new knowledge or assets</td>
<td>Strong commitments to existing technology and lower willingness to cannibalize existing product decreases a firm’s ability to assimilate new knowledge or assets</td>
<td>Strong commitments to existing technology and lower willingness to cannibalize existing product decreases a firm’s ability to reconfigure its business</td>
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<tr>
<td>Top management characteristics</td>
<td>Bantel and Jackson (1989), Furr et al. (2012), Gerstner et al., (2013), Maula et al. (2013)</td>
<td>Top management characteristics affect whether a firm is open to acquiring new knowledge or assets</td>
<td>Top management characteristics affect whether a firm is open to assimilating new knowledge or assets</td>
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<tr>
<td>Organizational structure</td>
<td>Afuah (2001), Argyres and Silverman (2004), Cozzar (2013), Kapoor and Adner (2012), Monteverde (1995), Monteverde and Teece (1982), Troyer (2017)</td>
<td>Vertical integration facilitates assimilation of new knowledge or assets</td>
<td>Vertical integration facilitates assimilation of new knowledge or assets</td>
<td>Vertical integration facilitates assimilation of new knowledge or assets</td>
<td>Better human capital integration facilitates a firm’s ability to reconfigure</td>
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REVIEW OF INDIVIDUAL ANTECEDENTS

Firm Size

Broad empirical research has shown the stylized result that small firms have a lower likelihood of survival than larger firms (Caves, 1998; Geroski, 1995). Despite this average result, the relationship between firm size and survival depends importantly on the life cycle of the industry and the technology involved. Analyzing the entry and exit of firms listed in Thomas Register of American Manufacturers, Agarwal and Audretsch (2001) showed that firms with larger entry size—measured by asset value—have higher likelihood of survival only in industries in their formative (i.e., early) years and for low-technology products (e.g., ballpoint pens and combination locks). The advantage stemming from entry size does not hold in mature industries or for high-technology products (e.g., antibiotics and rocket engines). Similarly, the effect of firm size on firm performance depends on the nature of technological changes. Large firms in worldwide floppy disk drive manufacturers were more likely to survive than smaller counterparts in the face of frequent incremental technological changes (McKendrick & Wade, 2010). Furthermore, larger firms are more likely to invest in incremental innovation (Henderson, 1993), and larger firms that introduce incremental innovations more frequently increase their likelihood of survival and market value, whereas smaller firms that bring about incremental innovations raise their chances of failure (Banbury & Mitchell, 1995).

The advantage of being larger in size appears mostly to derive from a heightened ability to commercialize new technologies. Large size is often correlated with possessing excess resources that can be used to commercialize a new product or service. This increased ability to commercialize yields the most value when it is easy to acquire the knowledge required for the new technology. This is why larger

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<tbody>
<tr>
<td>Stakeholders</td>
<td>Benner (2007, 2010), Benner and Ranganathan (2013), König et al. (2013)</td>
<td>Stakeholders hinder a firm’s ability to acquire knowledge or assets that is incompatible with a firm’s current technology</td>
<td>Strong ownership influence may increase rigidity and decrease a firm’s ability to reconfigure</td>
<td></td>
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</tr>
<tr>
<td>Ecosystem &amp; environment</td>
<td>Adner and Kapoor (2010), Afuah (2000), Chesbrough (1999), Jacobides et al. (2006)</td>
<td>A firm’s environment—including its competitors (e.g., suppliers, customers, complementors, and alliance partners) and national institutional factors—affects its ability to acquire knowledge or assets</td>
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entry size grants higher likelihood of survival for low-technology products (Agarwal & Audretsch, 2001), which are products for which it is relatively easier to acquire the necessary core knowledge to produce them. Put differently, larger size appears to enable firms to move across barriers that deter external acquisition of new knowledge.

Firm size, however, is a construct or measure that is confounded with many other firm characteristics. For instance, larger firms are more likely to be older and to have more experience. Thus, in addition to the effect of firm size on an incumbent’s ability to adapt to a given technological change that has been shown by aforementioned studies, firm size may have a different effect under different circumstances. Larger firms may be more likely to suffer from coordination problems, and this may hinder such incumbent firms from successfully adapting to a technological innovation even when they possess both the necessary core knowledge and the means of commercialization. This is a plausible proposition that fits well with Christensen and Bower’s (1996) and Tushman and O’Reilly’s (1996) recommendation for incumbent firms to adopt an independent department to deal with the coordination problem that may occur when trying to adapt to a technological change. The proposition, however, has not been tested empirically.

**Firm Experience**

Incumbent firms also differ in the degree of pre-entry experience and other relevant experience. Not all incumbents possess the same prehistory or experience (Sosa, 2013). Firms that existed before a technological change differ in terms of their experience, and the possession of relevant experience increases the likelihood of survival in a new market (Carroll et al., 1996). More specifically, whereas technology-specific R&D experience is lost in the face of a technological discontinuity, application-specific R&D experience may still offer a competitive advantage for incumbent firms (Eggers, 2014; Sosa, 2009).

Broadly speaking, firm experience affects adaptation in three ways. First, experience develops a firm’s adaptation capabilities, which is likely to come from an increase in a firm’s ability to commercialize a new technology. Incumbent firms that have experience entering a new market previously are both more likely to enter a new market and more likely to perform well in a new market. In the context of the disk drive industry, firms that had entered previous disk drive generations were more likely to enter new generations (King & Tucci, 2002). Mutual fund firms with greater prior experience entering new product categories subsequently produced higher quality funds when they again entered new categories (Eggers, 2012a). Such adaptive, dynamic experiences—related to the idea of dynamic capabilities discussed below—may affect the ability of the firm to assimilate new knowledge and reconfigure existing resources to capitalize on new technological opportunities.

Second, experience affects innovative capabilities through previous technological choices. Entrants to the U.S. TV industry that previously produced radios (i.e., incumbent firms in the home entertainment industry) had a higher TV market share and demonstrated longer survival than firms without such prior experience (Klepper & Simons, 2000). Radio experience made firms better in managing R&D in a new market created by technological innovation, and they generated more innovations in the TV market than firms without such experience. In flat panel displays, firms with plasma experience developed stronger glass handling capabilities that enabled them to be more successful if they did adapt to LCD (Eggers, 2014, 2016). Thus, experience with other technologies can still increase the firm’s base of knowledge, in line with Sosa’s (2009) concept of application-specific experience. Research also shows that technological choices and breadth of technological experience facilitates adaptation by allowing firms to recombine old and new technologies (Furr & Snow, 2015). Thus, firms can gain specific capabilities and knowledge through previous technological experience that can be redeployed to address new opportunities. More generally, broader previous experience with technology affects a firm’s absorptive capacity or the ability to exploit and assimilate new external knowledge (Cohen & Levinthal, 1990). In fact, adopting a new technology fast, in and of itself, is not sufficient to ensure successful adaptation. Having adequate technological capabilities is necessary to realize the value that comes from the early adoption of a new technology (Franco, Sarkar, Agarwal, & Echambadi 2009). Stated more generally, leveraging previous experience leads to higher performance in technological competition (Cattani, 2005). Thus, firm experience that builds innovative capabilities can be thought of as both increasing the firm’s existing technological knowledge base and increasing their ability to assimilate new knowledge.

Third, the firm’s experience with previous technologies has behavioral implications for its subsequent innovative efforts. Faced with a choice
between two competing technological options, firms that initially invest in the losing technology are less likely to build knowledge in the winning technology subsequently (Eggers, 2012b). More specifically, in the context of the flat panel display, firms that initially invested in plasma (the losing technology) built less knowledge in LCD (the winning technology) and were even less likely to invest in the re-emergence of plasma years later, showing that experience with a failed technology can affect the firm’s willingness to invest in other technologies. Thus, technological experience can not only build potential capabilities that improve innovation but can also affect organizational motivation to pursue other new technologies.

Complementary Assets

Research claims that incumbent firms are likely to enjoy advantages over entrant firms in the face of a technological change due to their superior commercialization capabilities or complementary assets (Teece, 1986), allowing them to overcome a lack of new and relevant core technological knowledge. In many cases, incumbent firms are more likely than entrants to possess useful complementary assets and, therefore, may be able to survive technological changes (Tripsas, 1997a), but only if the complementary assets still retain value.

The adaptive relevance of specialized complementary assets that are not devalued in the face of a technological change is well illustrated by Tripsas’ (1997a) study of the typesetter industry. Across a series of competence-destroying technological innovations, incumbent typesetters that possessed specialized complementary assets (e.g., sales and service network, proprietary font library) were able to adapt to the technological changes as long as the innovation did not devalue their complementary assets. For instance, the introduction of the digital cathode ray tube (CRT) phototypesetter was a competence-destroying innovation that did not devalue the specialized complementary assets of incumbent firms. Following such a change, new entrants to the industry only captured 16 percent of the market. After the introduction of the analog phototypesetter that both destroyed the existing competence of incumbents and devalued their specialized complementary assets, however, new entrants secured 89 percent of the market. Such valuable complementary assets can help firms acquire core knowledge needed for adaptation. Similarly, upstream complementary “assets” or complementary technologies can enable incumbent firms to pre-adapt to disruptive technological changes (Roy, Lmapert, & Stoyneva, 2017).

Incumbent firms can also use their specialized complementary assets to serve as appealing alliance partners for startups possessing requisite core knowledge but lacking complementary assets, and strategic alliances that bring firms with complementary assets together with firms that possess the necessary new knowledge increase new product development, which in turn leads to higher performance (Rothaermel, 2001).

Complementary assets, however, do not only affect a firm’s ability to commercialize technological innovations but also influence its motivation and incentive to enter new markets. A firm’s motivation to pursue a radical innovation is distinct from its ability to pursue that technology (Eggers & Kaul, 2017). When a firm’s core products are threatened or if a firm possesses the complementary assets that have value in a new market, the firm is more motivated to enter the market and attempt to acquire or access the necessary core knowledge externally (Mitchell, 1989). More specifically, firms in the diagnostic imaging industry that possessed industry-specialized assets such as direct distribution system were more likely to enter a new submarket within the diagnostic imaging industry. Complementary assets therefore act as prisms through which incumbents view technological opportunities, and if the complementary assets that the incumbent possess would increase its commercialization ability, the incumbent has an incentive to enter the new market in the first place (Wu, Wan, & Levinthal, 2014). Similarly, Eggers (2012b) showed that firm initially investing in the wrong technology but who also invested in fungible complementary assets was more likely to adapt to the technological change, presumably because they had the motivation to continue investing and overcome typical failure-induced biases. Thus, complementary assets do not only serve as the role of granting firms the ability to commercialize an innovation but also as the motivation to adopt the new technology and to acquire the necessary knowledge to begin with (Helfat & Lieberman, 2002).

An unexplored role of complementary assets is their effect on an incumbent firm’s ability to reconfigure its existing business. Possession of complementary assets that aid commercialization of new technology serves as an incentive to adopt that new innovation (Mitchell, 1989). The flip side of this finding may be that the possession of complementary assets relevant to the existing technology may
hinder an incumbent’s ability to reconfigure its existing resources to adapt to a new technology. Although this proposition is plausible, there has been, to our knowledge, no study that has explored this effect of complementary assets.

Commitments and Cannibalization

Another important antecedent that affects both the ability and the motivation of incumbent firms to adapt to new technologies revolves around the relationship between the new technology and the existing operations of the incumbent firm. Firms are more likely to adopt, or at least try to adopt, a new technology if it is consistent with the existing managerial commitments that they have made (Sull, Tedlow, & Rosenbloom, 1997). When incumbents have strategic commitments to the existing technology, they are less capable of changing strategies to the one that better suits the new technology (Rosenbloom & Christensen, 1994). That is, strong commitments to the existing technology lower a firm’s incentive and ability to overcome internal barriers, especially those hindering external acquisition of knowledge that serves a new technology and that would compete with the existing technology within the firm. The inertial effects of commitments manifest through two primary channels—inconsistencies from path dependence and fear of cannibalization.

In terms of inconsistencies and path dependence, incumbent firms that make commitments to the status quo by engaging heavily in process management activities for their existing technology are less responsive to an emerging technology (Benner, 2009). In the photography and paint industries, firms that engage in higher number of ISO 9000 certifications for their businesses (i.e., greater process management) are more exploitative in their innovative efforts (Benner & Tushman, 2002). Process management, although beneficial in stable contexts, is ill-suited for the purpose of adapting to technological changes (Benner & Tushman, 2003). Project performance during technological transitions is improved by experimentation (Iansiti, 1995, 2000), and the exploitative nature of process management hinders experimentation. Once process management is built into the operations, it acts as an inertial force (Hannan & Freeman, 1984) that hinders firms from making changes to adapt to a change in technology because commitments to the existing technology reduce the incentive for the focal firm to traverse internal barriers that hinder the acquisition of new core knowledge that would devalue the existing commitments. In contrast, integrative capabilities (e.g., effective communication and effective coordination) increase an incumbent’s likelihood of entry at the time of its first investment (Moeen, 2017).

At times, even early commitments to the winning technology hinder incumbent adaptation. Display firms making choices in flat panel technologies that invested too early in LCD (during the era of ferment) were slow to switch between the variants of LCD as the technology evolved, leading to lower product quality (Eggers, 2014; see also Christensen, Suárez, and Utterback (1998)). Early commitments to specific variants of LCD technology created an inertial force for the firm that prevented it from switching to a better form of LCD technology. An incumbent’s strategic position before a given technological change influences how it responds to that change (Benner & Waldfogel, 2016), and commitment to any given technology can be viewed as a factor that makes it difficult to move across the barrier that hinders acquisition of knowledge associated with a different technology. Existing capabilities can act as a source of rigidity (Leonard-Barton, 1992), and perception of a technological change as a threat further increases an incumbent’s routine rigidity (Gilbert, 2005).

In terms of cannibalization, it is important to note that firms need to be willing to cannibalize their existing sales and operations—the extent to which a firm is willing to reduce the value of their existing investments (Chandy & Tellis, 1998; Deshpandé & Webster, 1989). The willingness to cannibalize its existing business or investment is critical because an incumbent firm often finds it difficult to leave an existing customer base to serve a new set of customers demanding products associated with the new technology (Christensen & Bower, 1996). Entrants or the attackers have the advantage in developing and adopting technologies that cater to an emerging user base that is different from the user base that incumbent firms have been serving (Christensen & Rosenbloom, 1995). Because startups are less concerned about cannibalization, they tend to be more likely to survive than diversifying entrants in mature industries (Bayus & Agarwal, 2007). Spinoffs inherit knowledge from their parent companies (Klepper & Sleeper, 2005), and such incumbent knowledge may be the reason for fearing cannibalization.

To successfully adapt to technological change and commercialize an innovation, an incumbent firm must deal with the aforementioned forces of organizational inertia and be able to overcome the internal
barriers to external knowledge acquisition. Loose coupling of different business functions has been suggested one of the way in which incumbent firms can reduce inertia and increase performance after a technological innovation (Hill & Rothermehl, 2003). The idea is that firms need to form a stand-alone division that deals with the commercialization of the new technology to isolate the inertial forces generated by other parts of the company. Newly formed independent divisions will have a higher incentive to adopt a new technology than preexisting firm divisions because the new divisions would not be subject to the commitments that the firm has made in the existing technology. The firms that successfully adapted to disruptive changes in the disk drive industry are the ones that created organizationally distinct units to deal with the new product market (Christensen & Bower, 1996). Geographically dispersing research sites provide similar benefits to incumbent firms. Having geographically dispersed research sites not only gives incumbent firms the ability to develop different generations of technology in different locations but it also creates competition among research sites that spurs innovation (Tripsas, 1997b).

Cognition and Identity

Another set of factors that may either hinder or facilitate an incumbent’s adaptation comes from psychological antecedents (see Eggers & Kaplan (2013) for a review on cognition and capabilities). These cognitive factors highlight the role that managers or top executives play in shaping a firm’s direction in the face of a technological discontinuity, and research suggests that cognition affects each of the barriers noted in our model. The mental models of top management, measured by analyzing the text of letters to shareholders, influenced their firms’ patenting behavior in the pharmaceutical industry (Kaplan, Murray, & Henderson, 2003) and in the communications industry (Kaplan, 2008a)—firms with managers who paid more attention to the new technologies were more likely to begin investing in the new technologies. Of specific importance is the direction of managerial attention—Eggers and Kaplan (2009) showed that whereas attention to the new technology facilitated adaptation, attention to the old technology impeded adaptation. At the same time, managerial attention to the affected industry was also related to faster adaptation, presumably because these managers viewed the domain-specific change as especially relevant. These findings suggest a broad pattern around how the direction of attention affects the firm’s ability to acquire and integrate new core knowledge.

Managerial cognition also plays a role in resolving market side uncertainty. Although Xerox Corporation was incapable of profiting from its many innovations such as the Ethernet and a page description language, these innovations were later commercialized by its spin-off entities such as 3Com (Ethernet) and Adobe (page description language). This highlights the importance of having an appropriate business model that would lead to successful commercialization of the technology (Chesbrough & Rosenbloom, 2002). Some of the key attributes of a business model include identifying the right market segment, offering a clear value proposition and formulating a competitive strategy. Successful renewal entails linking an external change to corporate strategy (Barr, Stimpert, & Huff, 1992). In the absence of an adequate business model, an incumbent firm may be unable to adapt to a technological change even if it possesses all the necessary core knowledge associated with the innovation.

This inertial effect of business model conflict highlights the relationship between managerial cognition and the political process of the firm (Kaplan, 2008b). If the political process does not lead to cognitive frames that are appropriate for a new technology, the firm will be unlikely to adapt successfully. Polaroid, an established instant photography company, was unsuccessful in its transition from instant photography business to digital photography, not because they did not possess the necessary technological capabilities to produce digital cameras but because of erroneous beliefs that its management held, such as the belief that Polaroid can only make money on consumables that follow the razor stick-and-blade model (Tripsas & Gavetti, 2000). Thus, managerial cognition or attention may reduce a firm’s ability to commercialize a technological innovation even if it has the ability to acquire the necessary knowledge. The management’s persistence in the old business practices can prevent an incumbent firm from successfully reconfiguring the firm. Adequate cognitive frame or vision of management, however, can also reverse the firm’s fate and lead to successful adaptation (Rosenbloom, 2000).

Managerial attention or cognition about the existing and the emerging technologies is not the only cognitive factor that affects an incumbent firm’s ability to adapt to technological change. Cognition about resources, labeled “resource cognition,” also affects
a firm’s ability to successfully adapt (Danneels, 2010). Smith Corona, one of the largest typewriter manufacturers, was successful in leveraging its resource base to transition within typewriter product categories. The company, however, was unable to leverage its resources to enter the personal computer (PC) market because of a failure of management vision or cognition about the resources necessary to survive in the PC industry. More specifically, the management of Smith Corona failed to understand which existing resources could be leveraged in the PC market and which resources they needed to acquire externally to adapt to the new market.

Both managerial attention to existing versus emerging technologies and managerial cognition about resources affect a firm’s ability to traverse internal barriers that hinder integration of knowledge with means of commercialization. In appropriate managerial cognition regarding either a new technology or an incumbent’s existing resources makes it difficult to move across such a barrier and leads to situations under which an incumbent fails to adapt to a technological innovation even though it possesses internally both the knowledge and the means of commercialization that are necessary to adapt to the technological change.

Such cognitive frames or beliefs that may either hinder or facilitate incumbent adaptation to technological change need not always come from a firm’s top management. Values or beliefs shared by organizational members are also important to consider. The internal identity of an organization is defined as the organizational members’ understanding of what is core, distinctive, and enduring about the organization (Albert & Whetten, 1985). Technological changes that challenge such an identity may be difficult for organizations to adapt to (Kogut & Zander, 1996; Nag, Corley, & Gioia, 2007; TiPpsas, 2009). For instance, Linco, a company that identified itself as a digital photography company, had difficulty transitioning to a USB flash drive company, not because they did not have the technological capabilities but because the shift to a USB flash drive company was challenging their existing identity as a digital photography company (Tripsas, 2009). Thus, organizational identity can at times make it difficult to traverse internal barriers that deter external acquisition of means of commercialization. Prior industry affiliation also shapes a firm’s set of shared beliefs, which in turn may shape a firm’s behavior in a new industry that it enters (Benner & Tripsas, 2012). In general, these studies suggest that the cognitive frames employed by managers to understand the external context and the new technology have broad and far reaching implications for the ability and willingness to acquire, assimilate, and reconfigure knowledge and resources to adapt to technological changes.

### Top Management Characteristics

Studies taking the upper echelon perspective—the view that organizations are a reflection of their managers (Hambrick & Mason, 1984)—have examined characteristics of top management that affect a firm’s ability to move across internal barriers to external acquisition of knowledge. One such characteristic that has been shown to affect an incumbent firm’s technological decisions is a trait known as narcissism. Narcissism refers to a psychological clinical disorder that is characterized by excessive self-admiration, self-aggrandizement, and the tendency to see others as an extension of themselves (Ellis, 1898; Freud, 1914). CEOs with narcissistic traits are more likely to make large acquisitions (Chatterjee & Hambrick, 2007) and more likely to take excessive risk and are particularly sensitive to social praise (Chatterjee & Hambrick, 2011). For incumbent adaptation, pharmaceutical firms with highly narcissistic CEOs paid more attention to biotechnology if there was a stronger audience engagement with the new technology (Gerstner, König, Enders, & Hambrick, 2013). This increase in attention to biotechnology among highly narcissistic CEOs in turn led to an increase in the degree of biotechnology adoption.

Top management team demographics also play a role in incumbent adaptation. Banks with top management teams that had higher educational level were more likely to be open to innovations in its early stage of acceptance in the industry (i.e., weaker barriers to external knowledge acquisition) (Bantel & Jackson, 1989). Top management team’s attention to discontinuous technology is affected by the ties that they have. Top management that has heterophilous ties through corporate venture capital is more likely to pay timely attention to technological discontinuities, essentially weakening the barriers that hinder external knowledge acquisition (Maula, Keil, & Kahra, 2013). Top manager’s functional background may also be an important antecedent to adaptation, as managers with extra-domain expertise are more likely to undertake technological changes, whereas managers with more intra-domain expertise show more inertia (Furr, Cavarretta, & Garg, 2012).
These results on top management characteristics are similar to findings on managerial cognition. Therefore, although there has not been ample research on top management characteristics, we anticipate that existing work on the link between top management characteristic and cognition (Carpenter, Geletkanycz, & Sanders, 2004) may provide further insight into the effect of top management characteristics, via cognition, on an incumbent firm’s ability to adapt to a technological change.

Organizational Structure

Structure follows a firm’s strategy (Chandler, 1962). As market structure or environment changes because of technological changes, the adequate strategy and structure of a firm may also change. That is, certain forms of organizational structure may facilitate incumbent adaptation, whereas other forms of structure may hinder adaptation. The challenge is that little empirical research has specifically focused on structure and incumbent adaptation to technological change. Many empirical and modeling studies address the link between structure and innovation in organizations (Csaszar, 2013; Argyres & Silverman, 2004), but exactly how this relates to incumbent adaptation (a much more complex process than innovation alone) has been seldom explored and is a clear area where future work could contribute to this literature.

Of the limited research on structure and adaptation, the form of structure that has received the most attention is the degree of vertical integration. Vertical integration affects firm strategy (Harrigan, 1984, 1985), and transaction cost, such as supplier switching cost, affects whether a firm is vertically integrated or not (Monteverde, 1995; Monteverde & Teece, 1982). Although vertical integration is theorized to be ineffective when facing uncertainty from the possibility of technological obsolescence (Balakrishnan & Wernerfelt, 1986), Kapoor and Adner (2012) found that vertically integrated dynamic random-access memory (DRAM) manufacturers were faster to launch a new product generation than nonintegrated firms. The effect of vertical integration on a firm’s ability to adapt to technological change further depends on the nature of its vertical integration. In the face of a technological change, firms vertically integrated into the existing technologies perform worse than firms that are vertically integrated into the new technology (Afauh, 2001). Thus, as with many other antecedents, vertical integration can enable and inhibit organizational adaptation.

Other than vertical integration, there is a dearth of research on the link between organizational structure and incumbent adaptation. Some modeling work has looked specifically at adaptation by existing firms. For instance, Siggelkow and Levinthal (2003) theorized the degree of centralization affect a firm’s ability to explore and adapt. They proposed that temporary decentralization may be beneficial in the long run. Such effect of centralization would further depend on the degree of environmental turbulence, where decentralization would be the better structure in turbulent environment (Siggelkow & Rivkin, 2005). And, very recently, some empirical work has moved beyond vertical integration to assess other aspects of structure that may affect adaptation. Troyer (2017) explored the effect of human capital integration on a firm’s decision to adopt a new technology. She found that hospitals that directly employ physicians adopt new technology faster than hospitals that maintain an arm’s length contractual relationship with their physicians. It is clear that the link between organizational structure and incumbent adaptation to technological change is an important yet understudied aspect of the broader literature and presents a significant research opportunity.

Stakeholders

The factors that contribute to an incumbent firm’s ability or inability to adapt to technological change do not reside only within the boundary of the firm. There are factors that are external to the focal firm that also affect its likelihood of survival in a new market created by a technological innovation. Stakeholders, such as security analysts react more positively to incumbent strategies that build and extend their technologies, whereas analysts largely ignore incumbent strategies that bring in new technologies (Benner, 2007, 2010). Such analyst re-actions put pressure on incumbents to continuously exploit their existing technologies (Benner & Ranganathan, 2013, 2017). Thus, firms that have security analysts as an important stakeholder may be less likely to adapt to technological discontinuity than other firms for which security analysts have less influence. Family businesses may also show different adaptation patterns because of the influence of family owners. König, Kammerlander and Enders (2013) proposed that firms with stronger family influence will be slower to recognize but faster to implement (once recognized) a technological discontinuity. Because of the fact that family firms are
more likely to have rigid mental models, they are less likely to recognize a technological change. Yet, in family firms, there is less of a political resistance to the decisions made by the family owners. Therefore, once the firm recognizes a technological discontinuity, the firm is able to adopt the technology faster than other firms in which there may be stronger political resistance to the new technology. These studies together show that stakeholders affect a firm’s ability to adapt to a technological change, particularly how stakeholders determine a firm’s ability to acquire new knowledge and assets relevant for the new technology.

**Ecosystem & Environment**

Industry structure and the innovation ecosystem that a firm is embedded in also affects the focal firm’s ability to capture value from the innovation that it is introducing to the market (Adner & Kapoor, 2010; Jacobides, Knudsen, & Augier, 2006). In fact, resolving its internal innovation challenges is not sufficient for the innovating firm to create value. Instead, other innovating firms in the focal firm’s environment (e.g., suppliers, complementors) should resolve their own innovation challenges as well, for the focal innovating firm to accrue value from their innovation. Similarly, if a technological change devalues the existing capabilities of an incumbent’s competitors—“the suppliers, customers, complementors, and alliance partners with whom it must collaborate and compete”—the incumbent is less likely to perform well after a technological change (Afuah, 2000: 387). The decision to invest in a new technology itself depends whether the focal firm has market, alliance, or hierarchical relationship with its complementors (Kapoor & Lee, 2013). National institutional factors, such as technical labor market, venture capital market, and the structure of buyer–supplier ties also affect whether an incumbent can survive a technological change (Chesbrough, 1999).

Incumbent firms can form alliances with startups that can provide the necessary core knowledge to adopt a new technology (Lambe & Spekman, 1997; Rothaermel, 2001). Different approaches to technological sourcing can lead to different manifestations of incumbent adaptation to technological change. For instance, internal R&D efforts in the U.S. pharmaceutical industry during the emergence of biotechnology between 1981 and 1991 was associated with higher number of biotechnology patents, whereas external R&D efforts (e.g., acquisition) at that time was associated with higher number of biotechnology-based products (Nicholls-Nixon & Woo, 2003). Incumbents with old technology are also more likely to enter into alliance with younger firms with a new technology (Rothaermel & Boeker, 2008). Certain alliances facilitate adaptation to technological changes. For instance, semiconductor manufacturers in alliances with firms that possess the related patents in the emerging nanotechnology were faster to adapt to this new technological innovation, whereas alliances with traditional manufacturers actually impeded adaptation (Suh, 2017). Thus, external actors may also affect a focal firm’s ability to acquire the core knowledge associated with a technological innovation.

**Employee Mobility**

Given that our barrier model focuses on the ability of the firm to acquire and assimilate new, externally acquired knowledge, it makes sense that employee mobility and employment protection law that affects a firm’s ability to retain or hire employees are also antecedents that may affect an incumbent firm’s ability to adapt to a technological change. To our knowledge, there has not been any study that directly examines these antecedents’ role on incumbent adaptation to technological change. Yet, several studies have looked at the effect of employment protection, and hence employee mobility, on firm innovation with mixed findings. Losing employees has been pointed out as a source of technological disruption that has brought trouble to incumbent firms such as Walt Disney (John Lasseter leaving to join what became Pixar) and Seagate (Finis Conner leaving to found Conner Peripherals) (Felin, 2016). In line with this view, wrongful discharge laws that protect employees from unjust dismissal have been found to spur innovation and founding of new firms (Acharya, Baghai, & Subramanina, 2013). Employment protection law is argued to increase job security and enforceability of contracts, which in turn are thought to increase employee’s investment in innovative activities (Griffith & Macartney, 2014). Other studies, however, demonstrate that restricting employee turnover leads to lower innovative output (Franco & Mitchell, 2008). Enforcement of non-compete clauses—which constrains employee mobility—reduces entrepreneurship and innovation (Samila & Sorenson, 2010). As a potential answer to these competing findings, Keum (2017) has shown that firms that are more in need to adjust their resources (i.e., employee) suffer more in terms of their...
innovative outputs from legislations that restrict employee turnover. More specifically, lagging firms, which require more resource adjustment, suffer more from employment protection law than leading firms that require less resource adjustment.

The effect of employment protection law on incumbent firms’ ability to adapt to technological changes can be inferred from the findings of the aforementioned studies on innovation. If a technological change requires substantive adjustment in resources, employment protection law is more likely to impede an incumbent firm’s ability to adapt to that given change. If a technological change, however, does not require significant resource adjustment, employment protection law that restricts employee mobility is less likely to affect an incumbent’s ability to adapt. As pointed out by Felin (2016), technological disruption may be initiated by employees that leave an incumbent firm. Thus, providing job security or restricting employee mobility may also be a factor that inhibits technological disruption from occurring in the first place. Future research should explore these possibilities and try to directly investigate the role of employee mobility on a firm’s ability to adapt to technological changes.

How do Dynamic Capabilities Fit?

The aforementioned discussion focuses primarily on empirical studies. Such studies represent a “bottom-up” approach for studying incumbent adaptation, which focuses on the importance of individual, micro-level factors. By contrast, the mostly theoretical literature on dynamic capabilities has taken a more “top-down” approach by identifying a general process of adaptation that does not necessarily focus on the role of specific factors (Helfat et al., 2007). The definition of dynamic capabilities is the firm’s ability to respond to changing environment and create or reconfigure its internal and external competencies (Teece & Pisano, 1994; Teece, Pisano, & Shuen, 1997). It is also known as second-order capability or the capability to adjust first-order capability (Winter, 2003; Danneels, 2008). Teece et al. (1997) described dynamic capabilities to involve complex routines that support an efficient process that fosters adaptation. In later work, Teece (2007) further broke down the construct into three firm capacities: (1) capacity to sense opportunities and threats; (2) capacity to seize opportunities; and (3) capacity to enhance, combine, protect, and reconfigure assets. The capacity to sense is related both to the motivation to pursue a new technology (although the framework largely equates awareness and motivation) and to a firm’s ability to acquire the necessary knowledge of a new technology, and the capacity to enhance, combine, protect, and reconfigure assets is analogous to a firm’s ability to commercialize a technological innovation. A firm’s capacity to seize may refer to both its ability to acquire core knowledge and its ability to commercialize a new technology.4 Possession of complementary assets and knowledge has been suggested as one source of such ability (Helfat, 1997). It is clear that firms with more dynamic capabilities would be more likely to adapt to technological change, but the abstract way in which early work theorized about dynamic capabilities made it difficult to link the concept with the empirical, “bottom-up” studies discussed earlier.

This has begun to change as more recent dynamic capabilities literature has begun to highlight the role of managers in bringing about strategic change (Adner & Helfat, 2003; Teece, 2007). Dynamic capabilities are about “coordinating and adapting effectively to changing environments (Augier & Teece, 2009: 416; Cyert & March, 1963), and managers are thought to be the centerpiece of such capabilities (Helfat & Martin, 2015). This recent shift of focus on managers in the “top-down” approach of dynamic capabilities is in line with the “bottom-up” empirical studies that demonstrated how managerial cognition shapes the technological direction of a firm (Eggers & Kaplan, 2009; Kaplan, 2008a, Kaplan et al., 2003; Tripsas & Gavetti, 2000). Teece (2007) for one acknowledges that managerial cognition serves as the microfoundation—lower level explanation for the strategy of the collective (Felin, Foss, Heimeriks, & Madsen 2012; Felin, Foss, & Ployhart, 2015)—of dynamic capabilities. Building on this framework, Helfat and Peteraf (2015: p. 835) introduced the concept of “managerial cognitive capabilities,” which is “the capacity of an individual manager to perform one or more of the mental activities that comprise cognition.” Managers who have more effective cognitive capabilities are thought to possess

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4 A separate camp of the dynamic capabilities literature argue that dynamic capabilities take the form of simple rules with unpredictable outcomes, particularly in the context of high-velocity environment (Eisenhardt, Furr, & Bingham, 2010; Eisenhardt & Martin, 2000). Simple rules are thought to narrow problem scope, thereby increase efficiency, while leaving room for altering the specifics, which creates flexibility (Bingham & Eisenhardt, 2011). Such a perspective on dynamic capabilities has yet to be well incorporated with Teece’s camp on the concept.
dynamic managerial capabilities. This can manifest as the utilization of adequate heuristics in uncertain environments and as the controlled problem-solving approach in situations in which the use of heuristics is not sufficient. Such cognitive capabilities have value for all the components of dynamic capabilities (sensing, seizing, and reconfiguring/orchestrating assets).

Abundant “bottom-up” empirical work on the phenomenon of technological change and incumbent adaptation has reached a point where there is a plethora of findings without a coherent theoretical framework. Purely “top-down” theoretical discussion of the concept of dynamic capabilities is also replete but largely lacks an empirical base as the concept has been seen as unclear (Kraatz & Zajac, 2001), confusing (Winter, 2003), and even tautological (Williamson, 1999). Although later studies have offered more coherent definitions of the concept (Barreto, 2010; Helfat et al., 2007), purely theoretical discussion of the concept does not seem sufficient to clear up the ambiguities of different variants of the theory. We believe the literature and the concept of dynamic capabilities can benefit from incorporating the existing empirical work on technological change and incumbent adaptation to provide more empirical clarity of the specific factors that facilitate adaptation. Similarly, the overarching framework of the dynamic capabilities literature may help inform the largely disconnected empirical work on the phenomenon of incumbent adaptation to a technological change. Although there is a great deal of work to be done to bridge these macro- and micro-perspectives, Helfat and Peteraf’s (2015) work is one example that shows how the two literatures can be brought together to further our understanding. As we discuss in Section 5, however, one real challenge is that no given set of micro-level characteristics is likely to facilitate adaptation in all situations, meaning that a single, general concept of dynamic capabilities may be impossible to identify.

**OPPORTUNITIES: WHAT DO WE NOT KNOW?**

The previously mentioned review—framed around the four process stages of possession, acquisition, assimilation, and reconfiguration that allow incumbents to overcome internal and external barriers to adaptation—shows that we already know a great deal about incumbent adaptation to technological change. We know that firm size, experience, and complementary assets each may increase an incumbent firm’s likelihood of survival in a new market that it enters, but each through different stages in the adaptation process. We also know that inappropriate cognitive frame, managerial thinking, and organization identity can hinder an incumbent’s ability to adapt to technological changes, particularly by inhibiting assimilation and reconfiguration. Furthermore, the external actors of an incumbent firm such as stakeholders and family owners need to be accounted for to understand the incumbent’s ability to adapt as they affect the ability of the firm to acquire key resources and can affect willingness to assimilate and reconfigure. In this section, we seek to outline some specific suggestions for future research that emerge from our review of the literature.

First, from looking at Table 1, it is clear that there are important gaps in our understanding—antecedents that have been identified as relevant but that have not explored across the range of process stages. For antecedents such as firm experience, complementary assets, commitments, and managerial cognition, there is ample work that examines the antecedents’ effect on different types of barriers to adaptation. For other antecedents—especially those exploring the role of external actors such as institutions (affecting mobility) and the ecosystem—we do not have a comprehensive understanding of their effect on the different barriers. Existing studies have established that preexisting commitments reduce an incumbent’s incentive to adopt a new technology, but how this effect on motivation is related (if at all) to an incumbent’s ability to acquire new knowledge or on its ability to commercialize a technological innovation. We need to acknowledge that a certain antecedent may have effects at more than one stage of the adaptation process, and more work is needed to examine the differential effects of the antecedents. This is important to recognize as there may be more than one way for an incumbent to adapt to a given technological change (equifinality). More specifically, an incumbent can invest in a new technology through multiple means—internal research, external research, contracts, alliances, and acquisitions—and the existing barriers may affect which means an incumbent chooses and, such means of investment may affect the barriers as well (Kapoor & Klueter, 2015).

Second, note that each individual study discussed previously examines a single antecedent to incumbent adaptation as it affects a specific type of barrier at a specific stage in the adaptation process. For instance, Tripsas (1997a) focused on understanding how the *ex ante* possession of specialized complementary assets that are not devalued in the
face of technological discontinuity improves the incumbent’s ability commercialize the new technology, overcoming any external or internal barriers to the acquisition of new resources through their possession (although it does not provide comparable detail to the acquisition of requisite technological knowledge nor any reconfiguration necessary to adapt). Mitchell (1989), on the other hand, examined the role that specialized complementary assets plays in incentivizing incumbents to enter a new market. These studies together illustrate that possessing the right complementary assets increases the likelihood of incumbent adaptation, but the exact nature of the process and mechanism in each is importantly different. By combining studies that explore the same antecedent but that focus on different barriers or stages in the adaptation process, we can learn more about the effect of the specific antecedent. Put differently, if all four process stages are required for adaptation, then studies that explore the effect of an antecedent that do not account for how incumbent firms overcome all four stages are effectively underspecified. For example, if a study explores an antecedent that affects the ability (or motivation) to acquire and assimilate new knowledge, but does not discuss any barriers to reconfiguration within the firm that still could prevent complete adaptation, then it is unclear to what extent the antecedent should actually lead to adaptation. Future research should focus not only on a single stage in the process but the broader stages of adaptation to provide a more holistic picture.

Third, we also importantly lack a general understanding of how different antecedents to successful or unsuccessful adaptation moderate or interact with one another. This is due to the generally disconnected nature of existing studies, although there are some notable exceptions. For instance, Bayus and Agarwal (2007) extended Klepper and Simons’ (2000) finding that prior experience of incumbent firms increases the likelihood of survival and performance. Bayus and Agarwal (2007) added that this relationship between firm experience and survival is contingent on the stage of the industry. Eggers and Kaplan (2009) also examined the effect of managerial cognition and the effect of organizational capabilities concurrently to understand how they interact with each other to shape an incumbent’s technology adoption. By looking at multiple antecedents simultaneously, they were able to show the important finding that it is not necessarily organizational capabilities in the old technology that inhibit adaptation but managerial attention to the old technology. This finding would not have been visible if the authors focused only on cognitive antecedents to adaptation. Kaplan and Henderson (2005) further argued that organizational cognition and incentive are intertwined and that they coevolve. Taylor and Helfat (2009), in their study on IBM and NCR identified four influences on managerial linking activity: economic, structural, social, and cognitive. They theorized that these influences all have to be accounted for to understand how incumbent firms can successfully navigate technological transitions. Aside from these examples, however, the instances of studies building on prior studies and examining two or more antecedents simultaneously are rare. Instead, the existing studies have focused the main effects of different individual antecedents to incumbent adaptation. To move past a set of disconnected findings that do not adequately identify the underlying processes behind adaptation, future research needs to explore the effects of new antecedents in the context of existing antecedents to the extent possible.

Fourth, some antecedents may not only moderate one another (as discussed previously) but may also form a mediated causal relationship. Gerstner et al. (2013) showed that narcissistic CEOs are more likely to pay attention to a certain technology if there is higher audience engagement with the innovation. This finding illustrates a causal relationship among top management characteristics (e.g., narcissism), managerial attention, and technology adoption. They built on the finding that managerial attention directs the technological direction of a firm (Eggers & Kaplan, 2009; Kaplan 2008a; Kaplan et al., 2003), and they further showed that the effect of CEO narcissism on technology adoption is mediated by CEO attention. If either narcissism or CEO attention was studied in isolation of the other, we would not have been able to learn about the detailed causal relationship. Studying multiple antecedents simultaneously would enable us to uncover such causal chains that lead to incumbent adaptation. This would be especially helpful for future studies on antecedents such as age and experience that logically seem to work through other mechanisms (as the theory in these articles typically outline) but that have not been adequately explored. Empirically, this may speak to a need to consider multiple dependent variables more often, which would allow for a more careful exploration of the empirical relationships between variables. Only focusing on what drives (for example) profits or complete adaptation, as opposed to considering what may drive each stage in the
adaptation process such as knowledge acquisition, obscures the actual nature of the antecedents.

Fifth, the most problematic aspect of the present literature on the topic is that it predominantly focused on technological changes that by definition are ultimately the winning technology (Eggers, 2014, 2016). In other words, the existing studies examine technological innovations that incumbents need to adopt to survive. In reality, however, it is unclear for incumbents whether a certain innovation will come to dominate their existing technology a priori. Technological change is almost always accompanied by a significant degree of uncertainty. During its preparadigmatic phase, in particular, there is a lack of a dominant design (Dosi, 1982; Teece, 1986; Tushman & Anderson, 1986), and incumbents are faced with a dilemma between the less uncertain option of exploiting their existing technology and the more uncertain option of exploring one or more potentially new technologies. Not all technological innovations come to displace the existing technology—electroluminescent flat panel displays, Betamax video systems (Ohashi, 2003), and Laser-disc all come to mind. Thus, incumbent firms have to parse through multiple technological innovations that arise to find the truly promising one and then try to adopt or risk chasing many expensive and speculative technologies that end up being worthless.

What is unclear across existing studies of technological change and incumbent adaptation is whether the factors that research identifies as the antecedents to successful incumbent adaptation are simply factors that increase an incumbent’s responsive flexibility to any technological change or whether the factors selectively increase an incumbent’s responsiveness to the winning technology. For instance, it is unclear whether the possession of complementary assets increases an incumbent’s general likelihood of adopting any new technology (both winning and losing) or whether it only increases an incumbent’s likelihood of embracing technological innovations that will come to dominate their existing technology. To truly test whether a certain antecedent increases an incumbent’s ability to both identify a winning technology and adopt that technology, we need to test whether the antecedent also increases an incumbent’s likelihood of adopting an innovation that ultimately fails to displace the existing technology. This is especially vital to the extent that research seeks to offer practical implications for managers.

Finally, when considering future avenues for research around the specific antecedents of incumbent adaptation, it is important to note that the literature on technological change and incumbent adaptation has focused on exogenous technological changes for which incumbents either lack the knowledge, the means of commercialization, or both. Exogenous technological changes were assumed to be the most problematic for incumbent survival and, thus, the most relevant question to study from a strategy research perspective. This stream of research, however, may benefit from research on the recently burgeoning literature on technological exaptation.

**TYPOLOGIES OF TECHNOLOGICAL CHANGE**

As discussed earlier, much of the empirical research on incumbent adaptation to technological change has been focused on a single theoretical explanation (e.g., complementary assets, dynamic capabilities) that explains or predicts whether certain incumbent firms can or cannot adapt to any kind of a technological change. We believe this desire for the general theory of incumbent adaptation is likely as futile as Ahab’s obsession to kill the white whale. Technological change is a complex phenomenon, and one wave of change may be importantly very different from another. An incumbent’s ability to adapt to any given technological change will be as much contingent on the nature of the change itself as it is dependent on the characteristics of the incumbent firm. Thus, whereas all of the antecedents of incumbent adaptation discussed earlier would be expected to impact adaptation in some cases, none would be expected to be universally applicable in all situations.

For example, Tripsas (1997a) demonstrated that typesetter firms with specialized complementary assets that were not devalued (e.g., distribution channel and proprietary font library) helped them survive and thrive in a new technological generation. In the semiconductor lithography, however, incumbents had difficulty adapting even though the complementary assets that they possessed were not devalued by the change (Henderson & Clark, 1990). Similarly, generational changes in disk drives did not devalue complementary assets possessed by inert incumbent firms, but incumbents had difficulty adapting to some generational changes (Christensen & Bower, 1996). Thus, the possession of complementary assets ensures successful adaptation when facing a certain technological change but not for others because of the differences among technological changes.

We believe the nature of a given technological change needs to be examined in conjunction with
antecedents to incumbent adaptation to better identify and articulate boundary conditions in which a certain antecedent is sufficient for incumbent adaptation and when it is not. Because most existing research is single-industry studies, generalizing from one context to another is difficult. To facilitate discussions of generalizability, authors need to identify specific similarities and differences among technological changes. Prior research has used general terms such as radical and incremental (Abernathy & Utterback, 1978), disruptive (Christensen & Bower, 1996), and architectural (Henderson & Clark, 1990), but these terms are often applied with minimal relationship to the original concepts and do not necessarily facilitate cross-industry comparisons of antecedents to adaptation. Technological shifts may be radical for different reasons, meaning that different antecedents should be relevant. The sheer number of technological changes that have been studied has reached a point where it is too large to consider them all as similarly radical. Durand (1992) introduced the concept of “micro-radical” innovation to refer to technological changes that fall between incremental and radical innovations. Ansari and Krop (2012) also acknowledged that more granular classification of technological change is needed. We suggest the need for a granular, consistent approach for describing technological changes and seek to offer a set of guidelines for describing technological changes that build on the key aspects of the barrier model introduced earlier in this article. The goal is to push researchers to better document and describe the context of their study in a way that facilitates cross-context comparisons and to suggest that researcher should more directly theorize about boundary conditions. We briefly discuss the four aspects of our suggested typology below and then discuss how existing work on technological change fits within this typology.

First, innovations may differ by the degree of impact they have on incumbent firm’s existing core technological knowledge. Technology is the process of converting inputs to outputs, and technological change improves such process by lowering cost or improving outcomes (Mokyr, 1990). Yet, many studies define the technological changes that they examine to be radical without giving explicit considerations to the changes that they bring about to core technological knowledge (including the architectural structure of the knowledge). Logically, significant changes to the existing core knowledge require incumbents to make changes to its skilled labor (typically scientists and engineers) and/or patent portfolios. New technologies typically require new engineers and scientists with different skill sets from existing employees. Even if the same employees can work with the new technology, a significant change would mean that they would need to focus their efforts on a new technological domain (typically visible through the patent portfolio of the firm). If a technological change does not require either a change in employee skills or technological portfolio, then we would argue that it cannot represent a significant change in terms of core knowledge. Moreover, these changes in labor skills or technical knowledge may be additive (i.e., the firm needs to add new skills and knowledge but continues to need the existing skills and knowledge) or substitutive (i.e., new skills and knowledge replace all or part of the existing knowledge of the firm). Changes that require substitution (as opposed to only addition) are likely to be politically much more difficult for organizations to implement, creating additional challenges for incumbents to overcome. Research that clearly measures or assesses the degree of change in core technological knowledge using these two indicators of change (labor and knowledge), as well as describing the degree to which the change is additive or substitutive, provides a clear opportunity to understand how challenging such a change would be and facilitates comparison across other contexts. Whereas patents have already been used extensively as a measure of firm’s knowledge base (Cohen & Klepper, 1996; Henderson & Cockburn, 1994), the use of labor composition has not been used as extensively as a measure of a firm’s knowledge.

Second, technological changes may differ by the impact they have on the complementary assets that incumbent firms possess (Rothenmel & Hill, 2005; Teece, 1986; Tripsas, 1997a), and such changes have important implications for adaptation. Furthermore, technological innovations that require specialized complementary assets (e.g., ships and ports) rather than generic complementary assets (e.g., general manufacturing facility) are thought to favor incumbents already possessing such specialized assets over others that do not. Technological changes for which the existing assets that incumbents possess are not fungible are difficult for firms to adapt to (Danneels, 2010). And, as discussed in the barrier model, any assets the firm lacks may be more or less difficult to obtain externally in the market. Despite clear terminologies describing the role that complementary assets play in shaping incumbent adaptation, many studies have not incorporated the impact technological changes have on incumbent firms’ complementary assets and focused instead only on other factors (e.g., core knowledge). One potential
reason is that measurement of impact on complementary assets is less straightforward than measuring core knowledge. To assess whether a technological innovation requires specialized or generic assets and to understand whether or not a new technology devalues existing assets, researchers need to engage in qualitative work to offer informed (but clearly articulated) judgment calls informed by field work and consultation with industry experts. Although existing work on complementary assets has already followed this path (Danneels, 2010; Tripsas, 1997a), this has yet to be incorporated into the work by scholars focusing on other antecedents.

Third, technological changes may have differing degrees of impact on incumbent firms’ external actors, including suppliers, buyers, and complementors. Even if a technological change only modestly impacts an incumbent’s core knowledge and complementary assets, a technological change can be difficult to adapt to if it has a significant impact on its external actors. Adner and Kapoor (2010) showed that upstream technological challenges in components increase learning and benefit technological leaders, whereas downstream innovation challenges in complements delay technological adoption and bring less benefit to the leaders. Christensen’s (1997) theory of disruption can be understood as an innovation that has a significant impact on external actors. Most disruptive innovations do not entail significant changes to core or complementary resources but instead generate misleading signals based on feedback from the demand side (Adner, 2002; Danneels, 2004). These are two examples of how prior research has studied technological changes that produce significant impact on external actors to the firm. Although this does not mean that the consideration of the external actors needs to be the centerpiece of every study on incumbent adaptation to technological change, it does require researchers to carefully research and consider the potential of such an impact.

Whereas the three factors mentioned previously—core knowledge, complementary assets, and external actors—all derive clearly from the barrier model discussed earlier, there is one additional aspect of technological change that merits better description to improve comparability across studies. The emergence of a new technology is typically preceded by an era of ferment (Anderson & Tushman, 1990), in which technological uncertainty is high, products and competing standards proliferate (Utterback & Abernathy, 1975), and firms face difficult choices about resource allocation (Christensen & Bower, 1996). But the eras of ferment for different new technologies are markedly different as well. We see the distinctions along four lines. First, eras of ferment differ in their historical contexts, primarily in terms of how frequently new technologies had emerged in the past, and how often these technologies had been successful in coming to dominate the industry. Second, eras of ferment differ in the degree to which technological standards compete not just across generations, but also within generations. For example, liquid crystal displays were competing plasma and other display technologies for dominance in the flat panel market (Eggers, 2016), and fiber optics competed with wireless technologies in the communications hardware industry (Kaplan, 2008a). Third, in line with Christensen’s (1997) story around disruptive innovation, some eras of ferment are characterized by new technologies that are initially inferior to existing technologies, whereas in other cases, the new technology emerges already with a performance advantage. Finally, eras of ferment differ in their duration, as product and technological experimentation gives way to a new dominant design that provides more certainty for the industry’s evolution. This is closely related to Adner and Kapoor’s (2016a, 2016b) pace of technological substitution, in that higher uncertainty often arises when it takes longer for the true value of the substitute technology to emerge. Each of these four factors—context, proliferation, quality, and duration—all affect the level of uncertainty facing firms in the era of ferment. The implication would be that, in lower uncertainty situations, firms with dominant technological and complementary resources should dominate the new technology, whereas in the case of higher uncertainty situations, the firms that most deftly navigate the shifting tides in the industry would be most successful. Future research on technological adaptation should strive to offer a more complete picture of the prehistory of the new technological generation to assess relative uncertainty about whether any given new technology will be successful.

Classifying Technological Changes

The previous sections detail four aspects of classifying technological changes that we argue could be used to classify existing and future research contexts to provide more clarity around generalizability of the findings. In this section, we seek to provide examples by using the proposed typology scheme to explore the three most studied technological changes in the
literature: (1) the emergence of biotechnology in the pharmaceutical industry, (2) generational changes in the disk drive industry, and (3) the rise of digital photography. Although all three technological changes have been argued to be radical technological innovations, it is hard to argue that they are similar innovative changes. Our proposed framework allows us to show those differences explicitly and draw comparisons across contexts. Note that the discussions below are highly speculative as the authors of the studies exploring these contexts do not necessarily provide sufficient information for us to judge the four aspects of our framework—an example of the challenge that limits comparisons.

The emergence of biotechnology in the pharmaceutical industry is the most extensively studied technological change in the literature. During the 1970s, when scientists began to speculate about the potential of molecular biology, biotechnology was not compatible with existing beliefs of the established pharmaceutical companies. Incumbent firms feared that “it would lead to the development of bacteria containing cancer-causing genes that might spread to the human population” (Kaplan et al. 2003: 207). Incumbent pharmaceutical companies had been developing drugs based on chemical synthesis, and the new biotechnology paradigm rendered obsolete the existing method of drug discovery. Rothaermel (2001: 691–692) estimated that the skill loss that a scientist transitioning from the chemical-based drug development model to the biotechnology-based framework to be around 80 to 100 percent. Thus, the emergence of a biotechnology-based framework can be argued to have had a significant impact on the core knowledge of incumbent firms in the pharmaceutical industry and specifically that the required new knowledge would substitute for the traditional knowledge possessed by scientists. Presumably, this would mean that any incumbent firm seeking to adapt to biotechnology would need to both hire a new set of scientists and dismiss (or radically retrain) existing scientific human capital. Because the technology required such a distinct knowledge, it is plausible that the ability to acquire and assimilate new knowledge was critical to adapting to the emergence of biotechnology.

The impact of biotechnology on the complementary assets of incumbent pharmaceutical firms, however, can be argued to be minimal. The downstream complementary assets of pharmaceutical companies were not devalued from the transition from R&D based on chemical synthesis and trial-and-error to R&D based on molecular biology. The customers and web of stakeholders would remain the same, and while the sales force would need some retraining, the change would not be massive. Incumbent pharmaceutical companies maintained their market share by relying on complementary assets such as strong sales force and brand recognition (Gerstner et al., 2013; Rothaermel & Hill, 2005). Thus, the ability to access complementary assets may not have been much of a problem for incumbent pharmaceutical firms.

External actors in the pharmaceutical industry also seem to have been minimally affected by the emergence of biotechnology. There may have been changes in the supplier base for incumbent firms adopting biotech approaches, but given that most pharmaceutical inputs (other than labor) were relatively commoditized, this should not represent a significant challenge. As mentioned previously, the customers and complementors were also largely the same. The most significant change in terms of external actors would likely have been the change in reliance on universities as sources of knowledge. Incumbent pharmaceutical firms that were able to form alliances with startups, which enabled the incumbents to acquire the necessary knowledge associated with biotechnology, were able to adapt to the change (Rothaermel, 2001). This indicates that as long as an incumbent pharmaceutical was able to gain access to the core knowledge of biotechnology, they were able to survive the technological change. The other two dimensions of a technological change—complementary assets and external actors—played less of a role. The fact that most incumbent pharmaceutical firms survived the emergence of biotechnology hints that the impact on the two dimensions was not significant and suggests that changes only affecting core knowledge may not necessarily be traumatic for incumbents.

Other innovations in drug discovery technologies have occurred before the emergence of biotechnology, but their frequency was not very high. The primary drug discovery technology that preceded biotechnology was Merrifield’s method of chemical synthesis that significantly reduced the cost of building combinatorial libraries of chemical compounds (Gershell & Atkins, 2003). Although biotechnology became known in the late 1970s, it did not lead to a breakthrough that significantly lowered the cost of drug discovery until the 1990s (Kaplan et al., 2003). Thus, the technology had a relatively long era of ferment. Furthermore, between its introduction and its rise as the dominant drug discovery technology, biotechnology could be argued to
have begun as an inferior technology to chemical synthesis because of its high cost and uncertainty (Rothaermel, 2001). As a result, the biotechnology’s era of ferment entailed a relatively high degree of uncertainty.

The generational changes in disk drive represent another technological change that has received attention from numerous scholars. Between 1975 and 1990, the industry went through several generations of disk drive that involved changes to their sizes (14”, 8”, 5.25”, and 3.5”) and storage capacities. The established firms in the disk drive industry, however, did not have any trouble developing technologies necessary for all of the disk drive generations. Changes in the size of disk drives and increases in storage capacity were both types of technological advancement that did not significantly change the existing core knowledge of incumbent firms (Christensen & Bower, 1996). Furthermore, the changes in disk drive generations are unlikely to have devalued the complementary assets that an incumbent disk drive manufacturer possessed, such as distribution channel and brand name. The generational changes of disk drives, however, had a significant impact on the makeup of buyers. The composition of buyers of 14” disk drives differed from the type of buyers of 5.25” disk drives (Christensen & Bower, 1996; Christensen & Rosenbloom, 1995). The 5.25” inch disk drives were initially demanded by manufacturers of minicomputers, whereas the earlier generation of 14” disk drives mostly served the makers of scientific computers. As a result, incumbent disk drive manufacturers serving scientific computer manufacturers lacked the incentive to launch the 5.25” inch disk drives, even though they possessed all the necessary capabilities to do so. Because the generational changes of disk drives had neither a significant impact on the core knowledge base of incumbent firms nor a significant impact on their complementary assets, the incumbent firms in the industry were able to enter the new submarkets and perform well (King & Tucci, 2002). Yet, multiple generational shifts in disk drives meant that the industry experienced frequent eras of ferment. Furthermore, certain disk drive generations were initially inferior to the previous generation for the existing dominant customer base, which made it difficult for certain incumbent firms to adapt (Christensen, 1997).

The transition from chemical-based film photography to filmless electronic photography is another technological change that has been examined by multiple studies (Benner, 2009, 2010; Benner & Tushman, 2002; Tripsas & Gavetti, 2000). The rise of digital technology in photography significantly devalued the knowledge in chemistry-based photography. Digital camera technology involved conversion of light images to binary data, which was a completely different process than the process involved in chemistry-based film cameras (Benner, 2009). Despite the fact that the rise of digital imaging technology did not fit in with the existing chemical-based knowledge of camera manufacturers, incumbent camera producers did not have much trouble adopting the new technology. The incumbent firms, however, did have trouble commercializing the digital product. Tripsas and Gavetti (2000) argued that this was due to managers’ erroneous vision in generating a profit stream from their digital products. It, however, may also be due to the fact that the digital technology significantly devalued the complementary assets the incumbent camera companies possessed. Polaroid, for instance, believed in the razor/blade model that they had success with in their instant imaging business. The business model, however, was inappropriate for commercializing digital camera, possibly because the complementary assets, such as film manufacturing technology, that had value for the razor/blade model of business lost value when the firm tried to commercialize the digital imaging technology. Similarly, the external actors of incumbent photography firms may have been significantly impacted from the shift from instant photography to digital imaging. The razor/blade model, which was appropriate for the chemistry-based photography technology, is likely to involve different external actors than the business model for commercializing digital photography. Chemistry-based photography involved manufacturing thin-film coatings, and, as a result, the technology involved external actors such as film processors. Digital imaging technology had a significant impact on such external actors, in that the new technology obviated their role in the value chain. The era of ferment for digital imaging technology was relatively long. Boyle & Smith of Bell Labs created digital imaging device in 1969 and Kodak created a digital camera in 1975, but it was not until the 1990s that the technology really matured. Although there were not multiple different strands of digital imaging technologies that were in competition for the dominant design, digital imaging technology in its initial days produced images of quality that was inferior to the images produced through chemical imaging technology. Thus, digital imaging technology entailed relatively high uncertainty during its era of ferment.

Table 2 includes the major points discussed previously related to the similarities—and important
differences—between the technological changes facing the pharmaceutical, disk drive, and photography industries. We also include other technological changes that have been examined in multiple studies including the transition from plasma to LCD flat panel display, the fiber optics revolution in the communications industry, and the advent of the Voice over Internet Protocol (VoIP) in the telecommunications. Although the list of technological changes in Table 2 is not an exhaustive list of innovations that have been studied by existing work, they include most of the technological innovations that have at least two articles studying the phenomenon. Except for a handful of innovations such as the emergence of biotechnology, no one technological change has been studied by multiple researchers, which makes it difficult to generalize findings. For the technological innovations listed in the table, we have tried to assess their impacts on core knowledge, complementary assets, and external actors and have tried to describe the level of uncertainty that existed during their eras of ferment. These, however, are speculations based on the readings of the referenced articles and are not meant to be an accurate depiction of the technologies. We instead urge researchers who work on these specific industries to take more care in explaining these aspects of the technological innovations that they are studying.

These technological changes are fundamentally different from one another. For instance, the rise of

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* The complementary assets were not devalued for certain generational changes and devalued for others.
biotechnology is very different in nature from the generational changes of disk drive technology. The emergence of biotechnology in the pharmaceutical industry had a significant impact on the core knowledge of the incumbents. Rothaermel (2001) estimated the labor skill loss associated with this technological innovation to be between 80 and 100 percent. The generational changes of the disk drives had some impact on the incumbents’ knowledge base (Christensen & Bower, 1996; King & Tucci, 2002), but the magnitude of such impact is unlikely to have been as severe as the introduction of biotechnology had. Thus, it would be an unjustifiable simplification to lump these two very different technological changes under the same umbrella of “radical” innovation. Without a deeper analysis of the nature of technological changes, studies may reach a misleading conclusion about the generalizability of a certain organizational antecedent to incumbent adaptation. In fact, the factors that lead to successful incumbent adaptation may differ across different technological changes, and certain innovations may be easier for established firms to adopt than other technological changes.

Existing empirical studies have not explicitly considered the impact of a technological change in this systemic manner using a consistent coding scheme that is similar to the typology that we propose here. Analyzing the effect that a certain technological discontinuity has, in this manner, will inform us whether the finding of a single-industry-single-technological-change study may be generalizable to other contexts. Given the in-depth nature of these empirical studies, we believe that the scholars have all the necessary knowledge about the industries and about the technological changes that they study to dissect the impact of the changes on the four dimensions of our typology. Their analysis of the context only needs to be more explicit in considering the nature of the technological change.

Interdependencies between Antecedents and Changes

Both the dynamic capabilities literature and the phenomenon-driven empirical work on incumbent adaptation to technological change have sought a general theory of incumbent adaptation. Researchers have been trying to offer a set of factors that allow certain incumbents to adapt to any kind of a technological change. Considering how significantly different one technological innovation may be from another, it is unlikely that a single factor (or set of factors) guarantees adaptation to any changes. Looking for factors that allow incumbents to adapt to any technological discontinuities is as futile, and sometimes tautological, as looking for factors that ensure sustained superior firm performance. It is simply beyond our means to kill the white whale.

The obsession for the white whale of a general theory of incumbent adaptation is not only futile. The pursuit of a single answer also creates problems for deepening our understanding of the phenomenon. Even though the purpose of having a general theory is to bring different empirical findings together, it is unlikely to serve such a purpose in this context. There are numerous theoretical approaches that have been used to understand incumbent adaptation. Each of these approaches has their own framework of adaptation that is often not compatible with others. The discrepancies arise because each approach examines different technological changes that occurred in different industries. The existing divide in the dynamic capabilities between Teece’s camp and Eisenhardt’s camp is an instance of such discrepancies. Both of their theoretical arguments regarding incumbent adaptation are valid within the contexts that they focus on. Eisenhardt’s perspective of dynamic capabilities, in particular, may be the most applicable in entrepreneurial and high-velocity environments in which technological changes occur frequently (Eisenhardt, 1989; Eisenhardt & Martin, 2000).

A thought experiment can also demonstrate how the pursuit of a general theory of adaptation is unlikely to come to fruition. Consider two firms—firm A and firm B—that are identical in every way conceivable. Both firms have exactly the same characteristics (e.g., industry, size, and experience). Now, the two identical firms are hit with different types of technological changes. Firm A is faced with a technological change that involves knowledge that is significantly different from its existing knowledge base. This change, however, does not devalue the specialized assets that it possesses. Firm B, on the other hand, is hit with a technological change that does not have a significant impact on its existing knowledge base. The change instead significantly devalues the specialized complementary assets. Given these two different technological changes, even though firm A and firm B are identical firms, they are unlikely to be equally capable of surviving the different technological discontinuities that they are facing respectively. Researchers who seek a general theory of adaptation would claim that the factors that allowed firm A to adapt to the technological
change that it encountered would also allow firm B to adapt to the other technological discontinuity that it faced. Such a claim, however, is unlikely to be valid.

A potentially more fruitful alternative approach to studying the phenomenon of incumbent adaptation to technological change is exploring how the fit between antecedents to adaptation and the nature of the technological changes affect adaptation outcomes. In other words, we need to study whether an antecedent that was conducive to incumbent adaptation for a certain technological change contributes to successful adaptation to other technological changes as well. If an antecedent is not found to increase an incumbent’s ability to adapt to a particular technology, we then need to explore what was different about the innovation in question that made it particularly difficult for incumbents to adapt. Although such an approach is unlikely to lead to a general theory of adaptation, it would give us an extremely detailed understanding of the phenomenon, which would allow us to give tailored advice to practitioners. We specifically propose that the ability of an incumbent to adapt to hinges on the fit between the type of change and aspects of the firm that dictates ability to respond. This framework may help us move from industry-specific, idiosyncratic case studies to more generalizable knowledge. Although the question of generalizability will always follow any single-industry empirical work, researchers can offer more insight about the generalizability of their findings by better explicating the nature of technological change that they are studying. There cannot be two identical technological changes that each occur in different industries. There, however, may be two technological changes that share the same core characteristics that make them either easy or difficult for incumbent firms to adapt. Future works should try to uncover such core features of the technological change that they are studying. In addition, researchers can delineate the boundary conditions of their findings. Understanding the context in which a certain finding will hold and the context in which it may not hold will allow us to realize the gaps of the research, which subsequent works can fill. We hope that the tools and perspectives offered in this review provide the necessary starting point to move down this path.

CONCLUSION

To form a holistic view of the phenomenon of technological change and incumbent adaptation, we not only need to bring together the disconnected studies on the topic but also need to be able to say more about the many different technological innovations that are being studied. In that regard, the systemic review of the existing literature that identifies the antecedents that allow incumbent firms to traverse the barriers to successful adaptation and the typology of technological change are complementary to each other. To understand how the antecedents to successful or unsuccessful incumbent adaptation moderate or interact with one another, the understanding of the nature of the technological innovation is necessary. Thus, categorizing the technological changes that have been examined using the proposed typology is the first step that we need to take. Then, within the set of innovations that are similar in all four aspects of the categorization scheme, the antecedents to adaptation need to be studied in conjunction with one another.

Through our review, we sought to provide clarity and consistency around the types of technological change. It does not suffice to argue that a certain technological change is radical. Instead, future research needs to identify the nature of the technological change and uncover the degree of radicalness of the innovation that they study. Understanding the typology of technological innovation will then allow us to theorize about the necessary capabilities or strategies that incumbents need to successfully adapt to. Our proposed categorization of technological change may be one of the starting points.

This systemic review of the literature on heterogeneity in incumbent response to technological change should guide future doctoral students, junior scholars, and those beginning their interest in the phenomenon. Instead of these streams continuing to exist as independent streams of disconnected research, we hope that our approach will provide a way of understanding the full richness of the phenomenon of incumbent adaptation to technological change.

The question of what makes certain incumbents more likely to survive a technological discontinuity clearly matters from the perspective of strategy research. Addressing this phenomenological question will allow us to understand the changing value of resources that may contribute to theoretical perspectives such as the dynamic RBV (Helfat & Peteraf, 2003). It will also lend insights to the more general question that addresses a firm’s ability to renew itself strategically (Agarwal & Helfat, 2009). It is, however, less clear whether exploring the heterogeneity among incumbent firms in their abilities to adapt to technological changes has merit from a social.
welfare perspective. Schumpeter’s (1942) notion of creative destruction viewed the demise of incumbent firms and the rise of a new economic structure as a process of economic development that improves social welfare. Societies that foster creative destruction are also thought to become more productive and richer. In fact, what “keeps a capitalist engine in motion comes from the new consumers’ goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates” (Schumpeter, 1942: 83), and understanding the antecedents of successful incumbent adaptation, in general, may not be beneficial for the society as a whole, as important as it may be to individual managers of incumbent firms.

This may suggest that efforts to facilitate the adaptation and survival of incumbent firms facing technological change decreases incentives for innovation and destroys value. But there are at least two potential reasons why adaptation may—in the right circumstances—be socially beneficial. First, incumbent adaptation allows for preservation of investments in existing assets that prevents the need for duplication and may actually sustain value. For instance, incumbent firms are more likely to have established brands and may require little further advertising efforts to increase their brand recognition, whereas new entrants will have to build new brands. The demise of incumbents would also mean that the value of their brands is destroyed, and this would necessitate a duplication or redundant investment in brand building by entrants. It is debatable whether such investment would increase social welfare. Second, to the extent that proliferation of new entrants increases consumer uncertainty, which in turn could lead to a delay in the market acceptance of a technological innovation, it is unclear whether the replacement of incumbents leads to technological progress. Considering these possible scenarios, we believe that research on the phenomenon of incumbent adaptation to technological change is worth pursuing even from the social welfare perspective. Future research in this vein may attempt to uncover when incumbent survival is beneficial for the society and when it is not.

Incumbent firm to technological change is a complex phenomenon we believe that it should be accepted as such. Grand theories with far reaching applications are often desired in academia. Yet, they usually come at the cost of losing valuable details. A general theory of incumbent adaptation will undercut the rich details of the industries and of the technological changes that has been studied. We hope our review will allow researchers of the phenomenon to come to appreciate the value of exploring the details and understanding the different contingencies. Be wary of being obsessed with the white whale and explore the vast oceans.

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