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WHO CHANGES COURSE? THE ROLE OF DOMAIN KNOWLEDGE AND NOVEL FRAMING IN MAKING TECHNOLOGY CHANGES

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The foundations of established firms are laid when, early in life, venture executives explore dynamic landscapes in search of opportunities. During this search, the executive team processes information that might signal the need to change, and their cognitive flexibility in processing this information affects the likelihood of such changes. While executive backgrounds affect this information processing, current literature does not identify how executive backgrounds impact the extent of change a firm undertakes. Therefore, we compare the effects of teams dominated by domain insiders, domain outsiders, and complementary teams (blending insiders and outsiders) on the likelihood of different degrees of technology change. In an examination of the population of U.S. solar photovoltaic manufacturing ventures from 1992 to 2007, we find that teams with extra-domain expertise, particularly at the CEO level, undertake more significant technology change. By contrast, intra-domain expertise has an inertial effect on change: even when combined in complementary team configurations, domain expertise reduces chances of significant technology change. These findings expand the discussion of types and antecedents of organization change, top management team composition, and the psychological foundations of strategy. Copyright © 2012 Strategic Management Society.

INTRODUCTION

Because we often identify established firms by their stable product lines, we tend to forget that, early in life, these same ventures change course frequently as they search for attractive opportunities. For example, Google began as a library reference search tool before morphing into an OEM Internet search product and then eventually discovering its most successful product, AdSense (Vise and Malseed, 2006). Similarly, Symantec began life as an artificial intelligence company before morphing into a linguistics platform and later into the antivirus software that made this firm one of the world's largest software companies (Dorf and Byers, 2008). As these examples suggest, many high-potential ventures begin in unpredictable markets with new technologies and must search for attractive opportunities, while adjusting to shifts in competitors, products, and technologies (Bingham, Eisenhardt, and Furr, 2007; Rindova and Kotha, 2001). In this search, the executives who lead the venture play a crucial role in recognizing signals to change and redirecting the venture accordingly (Beckman, 2006; Eisenhardt, 1989b; Gruber, MacMillan, and Thompson, 2010). Indeed, the cognitive capabilities of the executive team, particularly their cognitive flexibility, may be a crucial determinant of strategic agility (Adner and Helfat, 2003; Eisenhardt, Furr, and Bingham, 2010).

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It is, however, unclear which executives are likely to have the cognitive flexibility to recognize and make changes.

On the one hand, executives with extensive domain experience may be cognitively flexible because they have rich domain knowledge. That is, domain insiders may be especially adept at recognizing and processing information about potential changes. Indeed, research on experts, defined as individuals with deep domain experience, suggests that they are more capable in understanding the underlying structural features of a problem (Chi, Glaser, and Farr, 1988; Ericsson and Charness, 1994), have superior pattern recognition skills (Chase and Simon, 1973; North *et al*., 2009), and develop more robust solutions to problems (Bingham and Eisenhardt, 2011; Hinds, Patterson, and Pfeffer, 2001) than novices. As a result, individuals with deep domain experience may have greater cognitive flexibility, or the ability to recognize and integrate information, such as signals to change (Eisenhardt *et al*., 2010; Furr, 2009). Thus, in unpredictable markets that often demand change, having a venture led by individuals with domain expertise may increase the likelihood of adapting in the search for a productive opportunity.

On the other hand, executives who bring experience from outside the focal domain may engage in novel framing that gives them the perspective to recognize and react to new information (Eggers and Kaplan, 2009; Gilbert, 2005; Kaplan and Tripsas, 2008). Although framing is often studied as problem formulation, such as threat versus opportunity, the decision makers' background also plays an important role in how they perceive and respond to new information (Kahneman and Tversky, 1979; Tversky and Kahneman, 1981). Because domain outsiders have a different background, they are likely to bring a different perspective to a new domain that allows them to see information in a new light (Beckman, 2006; Jeppesen and Lakhani, 2010), use new analogies that add new templates for action (Gavetti, Levinthal, and Rivkin, 2005; Reeves and Weisberg, 1994), and have lower affective commitment, which allows them to respond to pressures for change (Staw, 1976; Sull, Tedlow, and Rosenbloom, 1997).

Our purpose is to explore how the backgrounds of venture executives affect the likelihood of change by asking: which venture executives—domain insiders or domain outsiders—are more likely to make technology changes? We focus on technology changes because of their importance to many high-potential ventures as they search for viable opportunities. We examine this question using our unique longitudinal data set of the entire population of U.S. solar photovoltaic (PV) manufacturing ventures founded since the watershed year of 1992. The PV solar industry is particularly appropriate for several reasons. First, this industry attracts executives with widely varying industry backgrounds and so provides variation to explore our research question. Second, it has a rich set of evolving and competing technologies to transform solar energy into other energy forms, making technology change a frequent and critical strategic decision. A key advantage of this data set is its granular tracking of both executives and multiple technical change events for over 15 years. Thus, we go beyond the emphasis in the literature on founding conditions and single large changes to an evolving technology landscape in which entrepreneurs search for attractive opportunities by making a variety of small (competence enhancing), moderate (blended competencies), and major (competence destroying) technical changes over time.

We contribute to emerging literature on the cognitive foundations of strategy and entrepreneurship. A primary insight is that while all teams make minor changes, only teams with some novelty (domain outsider top management team members or CEOs) make moderate changes and only teams with extra-domain CEOs make major, competence-destroying changes. By contrast, teams composed of domain insiders exert a largely inertial effect on making technology changes. More broadly, we contribute to the organizational change literature by quantitatively tying executive background to the broader range of relevant changes, not just competence-destroying ones. We contribute to the top management team (TMT) literature by highlighting the essential role of CEOs in change, and we expand the discussion of the TMT as a distinct structural and social unit rather than just an aggregation of individuals. Finally, we offer boundary conditions on the value of expertise and insights into the microfoundations of ambidexterity, dynamic capability, and strategic agility.

THEORY AND HYPOTHESES

Prior research on managerial attention and cognition provides a foundation for our research question: what leads some venture executives to recognize and act on information signaling a potential change when others ignore it? Research on firms responding to

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technical shocks suggests that the attention executives allocate to problems shapes their likelihood of responding (Gavetti, 2012; Gavetti and Levinthal, 2000; Ocasio, 1997). One aspect of this 'attention' is the ability of decision makers to be flexible in recognizing and adjusting to the flow of information. In the cognition and psychology literatures, individual ability to respond to new information and adjust mental schemas has been labeled neural plasticity. It has been studied both as physical restructuring of neural patterns and as the ability to alter one's interpretive schema (Anderson, 2000; Hawkins, Kandel, and Siegelbaum, 1993; Shepherd, 1991; Smith, Ward, and Finke, 2009). In the organizations literature, the concept of plasticity has received less attention, with extant research focusing primarily on cognitive inertia among decision makers who fail to respond to technological shifts (Edmondson, Bohmer, and Pisano, 2001; Thomke and Kuemmerle, 2002; Tripsas and Gavetti, 2000). More recently, since many decision makers do initiate change in response to environmental shifts, research has begun to explore the factors that allow them to flexibly respond to new information and take actions such as initiate change (Bartunek, 1984; Dutton and Dukerich, 1991; Eggers and Kaplan, 2009; Gilbert, 2006; Kaplan, 2008; Smith and Tushman, 2005). This emergent literature suggests the importance of cognitive flexibility. Following prior work (Adner and Helfat, 2003; Furr, 2009), we define cognitive flexibility as the characteristics and processes that lead decision makers to recognize, interpret, and integrate new information and alter their perspectives. While there are many potential factors contributing to cognitive flexibility, an important but unexamined factor is the role that executive experience may have on executives' ability to initiate change. Specifically, what role do executive backgrounds have on important strategic actions such as technology change?

While organizations face many pressures and many types of change, technology changes are some of the most crucial and difficult to make. Early organization theorists argued that technology represents one of the core features of organization and, therefore, a firm's technology is often buffered from and resistant to change (Thompson, 1967). Nonetheless, in the search for an opportunity, ventures must often change their technology as they encounter surprises in development or as the opportunity landscape shifts. Some of these changes are easier for executives to recognize and integrate because they enhance the firm's existing competencies (Abernathy and Clark, 1985). However, other technology changes are much more difficult for executives to recognize and integrate because they destroy the firm's competencies: specifically, they 'require new skills, abilities, and knowledge in both the development and production of the product' (Tushman and Anderson, 1986: 442). For example, the shift from discrete to integrated circuits or from audio cassettes to compact discs required the destruction of many old product and process competencies and the creation of new ones. Yet other changes fall somewhere between competence destroying and competence enhancing on the spectrum of technology changes. Executive backgrounds, specifically their experience in an industry, may play an important role in recognizing and initiating competence-destroying or competence-enhancing technology changes.

One argument suggests that executives with deep domain experience have many advantages in recognizing and making changes. Not only do domain insiders[1] have significant knowledge about the context (Eisenhardt and Santos, 2006; Grant, 1996a, 1996b), but the depth of their domain knowledge may provide them advantages similar to those identified in the expertise literature. Experts are defined in the psychological and organizational literatures as having a high level of domain knowledge (Benner and Tushman, 2003; Chi *et al*., 1988; Ericsson, 2006; Ericsson and Charness, 1994). Prior research demonstrates that as individuals gather more experience, they develop both greater knowledge (nodes in their knowledge network) and more connections between that knowledge (connections between nodes) as compared to novices with little experience (see Ericsson, 2006, and Dane, 2010, for a review). These knowledge characteristics, many of which domain insiders may share, provide experts with advantages in perceiving underlying problem structures, recognizing patterns, and developing solution representations that may increase the likelihood of recognizing information signaling a needed technology change.

First, experts have increased ability to understand the underlying structural features of a problem. This ability could provide advantages for decision makers

[1] In this article, we refer to individuals with primarily domain experience as domain insiders or intra-domain, synonymously, whereas we refer to individuals whose primary experience comes from outside the focal domain as domain outsiders or extra-domain, synonymously.

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recognizing information about change. Prior cognition research highlights that as individuals gain experience in a domain, they learn to focus on the critical dimensions of that domain (Ericsson, 2006). Specifically, experts develop the ability to recognize the underlying structural features of a problem whereas novices tend to perceive only the surface features of a problem (Chi *et al*., 1988; Gitomer, 1988; Hinds *et al*., 2001). For example, Chi, Glaser, and Rees (1982) observed that physics experts sorted problems based on their underlying structural similarities (i.e., laws of physics) whereas novices sorted problems based on their surface similarity (e.g., whether the problem involved springs or balls). Similarly, in the context of a firm, when decision makers have significant domain knowledge, they may have greater ability to recognize underlying structural features and, thus, an advantage in understanding new information about the environment or technologies that increases the likelihood of change. For example, in our context, while PV solar technologies may have surface differences (such as different chemical elements), they all rely on the same basic physics of transforming solar energy into other forms of energy.

Second, due to their extensive knowledge, experts have greater pattern recognition capabilities that allow them to process information signaling the need to change quickly and effectively. Research in cognition suggests that experts excel at pattern recognition because their deep, extensive knowledge allows them to see patterns that a novice might miss and to anticipate future events (Ericsson and Charness, 1994; Knowlton, 1997; Newell and Simon, 1972). For example, studies of tasks such as watching soccer matches or playing chess demonstrate that experts usually recognize more accurate patterns in the flow of information and anticipate future events more correctly than novices (Chase and Simon, 1973; North *et al*., 2009). Similarly, in organizations, domain insiders may be more capable in noticing new information and can 'connect the dots' between existing information so as to recognize emerging patterns (Baron and Ensley, 2006; Shane, 2000). For example, in an experiment where experienced executives gave a narrative evaluation of a new opportunity, Grégoire, Barr, and Shepherd (2010) found that more experienced executives have much richer pattern recognition skills.

Finally, prior work in memory, cognitive schema, and prototype theory highlights that because of their domain knowledge, experts often develop more robust representations and solutions to problems which may help them recognize and act upon new information (Baron and Ensley, 2006; Chase and Simon, 1973; Whittlesea, 1997). For example, in studies of novices and experts, researchers found that although novices excelled in developing concrete solutions to routine problems, experts excelled in creating flexible solutions to more complex problems (Bassok, 1990; Bassok and Holyoak, 1989; Hinds *et al*., 2001). Similarly, in organization settings, executives with domain experience may also develop more robust representations and solutions to problems that ultimately increase the likelihood of technology change. For example, Bingham and Eisenhardt (2011) studied what executives learn from their experience and found that as they gather more experience, they develop and continually adjust robust heuristics, which help them capture new opportunities flexibly and effectively.

In summary, based on findings about the role of domain experience in the expertise literature, it seems likely that domain insiders may benefit from better perception of underlying structural knowledge in their focal domain, better pattern recognition and anticipation of the future, and more robust solution representations. These are likely to increase their ability to be cognitively flexible in the incorporation of information from an unpredictable environment and, thereby, increase the likelihood of technology change.

At the same time, despite these many benefits, when considering the types of technology changes that firms face, changes that enhance firm competencies may be easier for domain executives to recognize and integrate than changes that destroy firm competencies. Prior literature argues that individual backgrounds shape the way individuals frame the relevance of information, and individuals have a tendency to filter information that matches their existing knowledge set (Kahneman and Tversky, 1984; Kaplan and Tripsas, 2008; Plous, 1993). Therefore, precisely because domain insiders have deep knowledge of the context and often a particular technological approach, they may be more likely to recognize and react to information that enhances their own or the firm's existing competencies while filtering out information about competence-destroying changes (Christensen and Bower, 1996; Tripsas and Gavetti, 2000). As a result, while domain insiders may have characteristics that increase the likelihood of change, they may be most likely to make competence-enhancing technology changes.

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Hypothesis 1 (H1): Top management teams whose CEOs and other members have domain expertise are more likely to undertake competence-enhancing technology change.

Domain outsiders and novel framing

An alternative argument suggests that domain outsiders are particularly likely to recognize and make technology changes. Although the psychology literature often contrasts experts and novices, a third category of individuals—namely domain outsiders—may play an important role in how firms process information and change. Unlike novices that lack knowledge, domain outsiders often have significant and diverse experience, but that experience is outside the focal domain.[2] Although domain outsiders do not have deep domain knowledge like domain insiders, they bring different knowledge and perspective that may increase their ability to recognize and make changes. First, because domain outsiders bring a novel perspective, they may engage in novel framing that allows them to recognize changes (Gilbert, 2006; Holbrook *et al*., 2000; Sull *et al*., 1997). Framing has been defined as the interpretive filters that allow individuals to recognize and act on information (Kaplan and Tripsas, 2008), and it is rooted in the backgrounds of executives (Tversky and Kahneman, 1981). Simply because domain outsiders come from a different area, they may recognize information signals that industry insiders do not see. For example, Jeppesen and Lakhani (2010), studying innovation contests, found that individuals who were technically or socially distant from the focal problem were more likely to solve intractable scientific problems precisely because they had a novel perspective. Similarly, Shah and Tripsas (2007), looking at the role of user innovation, observed that user-entrepreneurs brought a different perspective than experts, which allowed them to see industry problems in new ways. In the context of venture management teams, Beckman (2006) demonstrated that founding teams composed of individuals with diverse prior company affiliations led to an increase in innovation because they provided a new perspective. Therefore, when ventures are led by domain outsiders, they may engage in novel framing that increases their ability to recognize new information (Okhuysen, 2001; Okhuysen and Eisenhardt, 2002). Therefore, ventures led by venture executives from outside the focal industry may increase the likelihood of technology change.

Second, individuals from outside a focal domain often bring analogies that can increase the likelihood of recognizing and making changes. Whereas outside perspectives provide a different vantage point, analogies differ in that they represent the conceptual templates for action. For example, a supermarket analogy inspired Charles Schwab to reinvent the mutual fund industry as a supermarket of funds sharing costs (Kador, 2002). Research has suggested that analogies play an important role in the ability of managers to adapt because analogical reasoning provides templates for understanding and acting (Gavetti *et al*., 2005; Reeves and Weisberg, 1994). Because individuals from outside the focal domain have experience in other industries, such outsiders may bring diverse analogies. When combined with existing analogies, these new analogies provide a broader repertoire of templates with which to understand the industry and create novel recombination (Dane, 2010; Hargadon and Sutton, 1997; Taylor and Greve, 2006), thus increasing the ability of decision makers to recognize and make changes. Indeed, while the literature on expertise indicates that prior experience shapes pattern recognition, more recent research suggests that broader experience may increase the likelihood that decision makers integrate new information as relevant to the current context, which could increase the likelihood of technology change (Grégoire *et al*., 2010).

Third, domain outsiders may have lower affective commitment, which allows them to be more flexible in considering signals to change (Staw, 1981). Affect plays an important role in the ability of individuals and teams to make changes, and decision makers can become affectively committed to a particular approach, decreasing their ability to change course (Barr, Stimpert, and Huff, 1992; Holbrook *et al*., 2000; Sull *et al*., 1997). Because domain outsiders are unlikely to have similar attachments to an intra-industry solution, having domain outsiders in the decision making process likely decreases the affective commitment to a prior course of action, thereby increasing the ability to make changes if necessary (Fiske and Taylor, 1991; Huy, 2002). For all these reasons, although domain outsiders bring different experiences to the venture, their varied experiences may increase their ability to recognize and make

[2] Although both novices and domain outsiders lack experience in the focal domain, the amount of variety of domain outsiders' experience in other domains plays an important role in their ability to recognize change, and this distinguishes them from the classical stereotype of a novice as lacking experience.

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technology change. However, because domain outsiders bring novel perspectives, different analogies, and lower affective commitment, they may be particularly likely to recognize and make competence-destroying changes. Specifically, when facing an uncertain and dynamic environment, domain insiders may filter out the signals of change that destroy their competencies, but because domain outsiders are less cognitively and emotionally tied to a particular competence, they may be particularly likely to make changes that disrupt existing competencies.

Hypothesis 2 (H2): Top management teams whose CEOs and members have prior experience outside the firm's domain are more likely to undertake competence-destroying technology change.

Complementarity and change

Finally, it may be that teams including both intra- and extra-domain executives are the most capable of flexibly recognizing relevant information and making changes. In support of this possibility, several theoretical perspectives suggest that knowledge complementarity can lead to innovation and enhance performance in an organization (Eisenhardt and Santos, 2006; Galunic and Eisenhardt, 2001; Helfat, 1997; Katila, 2004; McEvily and Chakravarthy, 2002). The top management team literature has demonstrated that team diversity can increase performance (Carpenter, Geletkanycz, and Sanders, 2004; Eisenhardt and Schoonhoven, 1990; Hambrick, 2007) and lead to change in established organizations (Wiersema and Bantel, 1992, 1993). Therefore, a team containing both domain insiders and outsiders may be able to access the benefits of domain knowledge as well as the benefits domain outsiders bring, including novel framing, which increase the likelihood of change. Specifically, while an intra-domain CEO may possess capacity to recognize structural problem features, a TMT from outside the domain may introduce novel framing that allows the team to recognize many needed changes. Similarly, a CEO from outside the domain working alongside an intra-domain TMT may recombine knowledge in complementary ways (Beckman and Burton, 2011), which increases the likelihood of making many types of technology change.

Hypothesis 3 (H3): Complementary top management teams whose CEOs and/or members include a combination of domain insiders and outsiders will be more likely to undertake both competence-enhancing and competence-destroying technology changes.

DATA AND METHODS

Setting and population

Our research setting is the population of photovoltaic (PV) manufacturing ventures founded in the United States from 1992 to 2007. The solar PV industry represents an ideal setting for the study of antecedents to change because of the variety of executives attracted to the industry and its rich ferment of technologies. The solar industry initially emerged in the 1960s with the development of the first commercial solar panels, and it experienced an intense burst of activity during the oil crisis of the 1970s. However, after the oil crisis, solar PV became less viable as it was a very expensive source of power: PV power, even without installation costs, was more than 20 times the comparable cost of coal-generated power (Bradford, 2006). As a result, when government support evaporated, the industry collapsed, leading to the death of the industry (no significant producers remained in the U.S.). However, in 1992, the U.S.'s Energy Policy Act and the United Nations Framework for Climate Change (which eventually became the Kyoto Protocol) led to the reestablishment of government support that fostered a rebirth of the PV industry.

Since the reemergence of the industry, multiple parallel technology categories have developed concurrently (see Bradford, 2006, and Lynn, 2010, for an extended description of these categories), with one sometimes leading another but without convergence to a clear 'winning' technology (Mehta, 2010; Woody, 2010). Indeed, industry research confirms that both the internal (company) and external (industry) dynamism continue, with some observers noting that the industry is becoming more multifaceted and complicated (Mehta, 2010). Table 1 summarizes the technology categories in the industry. It also provides a brief definition of each category, its primary target markets, and examples of different types of technology change. Table 2 illustrates the timing of venture entry by year and technology type. While these data highlight the distinct technological categories (based on chemistry and structure), it is important to note that they all rely on the same

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Table 1. Solar photovoltaic technologies

Technology area	Technology category	Technology category description	Typical market	Major tech change example	Moderate tech change example	Minor tech change example
Silicon wafers	**Silicon (c-Si)**	• Crystalline silicon • 150+ microns thick • Ingot manuf. Process	• Residential, commercial, utilities	• Change tech category from c-Si to CIGS	• Change to cell (e.g., cell texturing; back contacts)	• Change to cell size (e.g., from 5 to 6 inch) • Change to wattage
Thin films and concentrators	**Amorphous silicon (a-Si)**	• Non-crystalline silicon • Thin (3–4 microns) • Spray manf. Process	• Residential, commercial, utilities	• Change tech category from a-Si to CdTe	• Change to cell (e.g., from single to multi-layered a-Si cell)	• Change in module size; add anti-reflective film
	Cadmium telluride (CdTe)	• Cadmium • Thin (1–3 microns)	• Residential, commercial, utilities	• Change tech category from CdTe to c-Si	• Chemistry reformulation • Novel contacts	• Change in module size; add anti-reflective film
	CIGS	• Copper, indium, gallium, diselenide • Thin (<10 microns thick)	• Residential, commercial, utilities	• Change tech category CIGS to nano-materials	• Chemistry reformulation • Novel contacts	• Change in module size; add anti-reflective film
	Low power concentrator	• 2–25x concentration • Low x light concentrators • Use single junction PV cells	• Residential, commercial, utilities	• Change tech category low conc. to organic	• Change to design (e.g., shift from lens to mirror)	• Change in application • Change in materials
	High power concentrator	• 25x–1000x concentration • High x light concentrators • Use multi-junction PV cells • Tracking systems	• Commercial, utilities	• Change tech category high cone. to c-Si	• Change to design (e.g., shift from 500 to 800x)	• Change in materials (e.g., from glass to metal mirrors)
	Multi-junction cells (MJC)	• Multiple junctions (band gaps), materials (GaAs, etc.)	• Commercial, utilities, niche	• Change tech category from MJC to a-Si	• Chemistry change (e.g., new semiconductor material)	• Change in cell size or application (e.g., from 1 to 2 inch cell)
Advanced materials	**Organic**	• Conductive plastic solar cell	• Residential, commercial, utilities	• Change tech category from organic to CIGS	• Chemistry change (e.g., new semiconductor material)	• Change in cell size or application (e.g., from 4 to 5 inch cell)
	Dye-sensitized	• Titanium oxide solar cell • Mimics photosynthesis	• Commercial, utilities	• Change tech category from dye cells to c-Si	• Chemistry change (e.g., new semiconductor material)	• Change in cell size or application (e.g., from 4 to 5 inch cell)
	Nano-materials	• Nano-modified materials (Si, Cd, etc). • <100 nanometer structures (nano antennaes, wires, dots)	• Residential, commercial, utilities	• Change tech category from nano-materials to CdTe	• Chemistry change (e.g., new semiconductor material)	• Change in cell size or application (e.g., from 4 to 5 inch cell)

Table 2. Entrants by technology category and year (based on final technology category)

Technology category	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
Silicon (c-Si)		1								1	1			4	1	8
Amorphous silicon (a-Si)					1					1	1	1	2	2	2	10
Cadmium telluride (CdTe)					1		1				1			1	1	5
CIGS				2					3				3			8
Low power concentrator	1		2			1				1	1	1	3	1		11
High power concentrator							1	2		1		1	4	1		10
Multi-junction cell (MJC)		1						1					1			3
Organic										1				1		2
Nano-materials									3			1	1	3	3	11
Total	1	2	2	2	2	1	2	3	6	5	4	4	14	13	7	68

underlying physics for the conversion of solar energy into other forms of energy.

We study the population of all 68 active and inactive PV manufacturing ventures founded in the U.S. from 1992 (year of the rebirth of the industry) to 2007, including firms that exited (such as by failure or acquisition). The data-gathering process began by refining the research question and hypotheses through interviews at 16 technology firms from a broad range of industries, followed by interviews with six solar PV firms from which three detailed cases were developed using standard qualitative research methods (Eisenhardt, 1989a; Eisenhardt and Graebner, 2007). These interviews informed the research question, research design, and measures for this quantitative study. We then collected data from the National Renewable Energy Lab (NREL), Department of Energy (DOE), VentureXpert, solar industry research firms (e.g., Photon, ENF, Solarbuzz, Greentech Media), industry associations (e.g., Solar Energy Industry Association), PV News (the single longitudinal industry publication), government grant documents, and archival company data. A key advantage of our data is that we include the entire history of changes in management teams and technologies for each venture and for each quarter since founding, yielding an unusually precise record of management team and technology changes, while avoiding potentially confounding sample selection and cross-industry effects.

Measures

Dependent variable

The primary dependent variable is a technology change in the venture's PV product portfolio. We measure this event as a binary variable equaling '1' when a change occurs and '0' otherwise. We track these changes quarterly throughout the history of the venture, until the end of the study in 2007 or an exit event (i.e., failure or acquisition). We determine when a technology change occurs based upon product development announcements and product descriptions as reported in primary and secondary documentation (press releases, product documentation, future product announcements, company histories, or funding requests). Because solar products can take years and significant resources to develop and commercialize, it is standard practice for firms to announce a technical change in a product well before the product's market introduction. Because

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new ventures and the industry are in an early development stage and face public and private scrutiny, product development announcements provide the most reliable and accurate measure of when a venture makes a technology change. As an example, when a venture focusing on low-power concentrators announces the development of CIGS thin-film solar cells, we recorded a change event. To observe changes, we tracked products over the life of the firm and measured a change when we could verify it with two or more sources. In most instances, the timing of technology change was consistent across reports, but in the few cases (well under 10 percent) with differences, we used the earliest event date reported. We counted each type of change (add, modify, drop) because prior research has highlighted that both established firms and ventures struggle with all types of change, including modifying or abandoning products within their portfolios (Holbrook *et al*., 2000; Rosenbloom, 2000; Sull *et al*., 1997; Thomke and Kuemmerle, 2002). As a robustness check, we tested the effects on each of these actions separately (add, drop, and modify) and obtained similar results to those obtained when all change events were combined.

A key advantage of our study is that we are able to capture a range of sizes of technology change, not just one type of change, such as competence-destroying changes. Early work on technology change recognized that competence-destroying and competence-enhancing changes represent ends of a spectrum of technology change (Abernathy and Clark, 1985; Tushman and Anderson, 1986). Scale differences have critical operational and strategic implications. We wished to understand whether executives with different domain experience and, therefore, presumably different knowledge and cognitive responses, differentially influenced the scale of technical change. Therefore, we divided the dependent variable into three sizes of change—major, moderate, and minor—based on the degree to which a change destroyed or enhanced existing firm competencies, operationalized based on Tushman and Anderson's (1986) definition of the degree to which a change requires new skills and knowledge. We argue that major changes are the most competence-destroying changes in our sample, minor changes are the most competence enhancing, and moderate changes have elements of both competency enhancement and destruction. In making these distinctions, we first relied on archival industry sources to determine an initial demarcation. We then used a panel of six individuals that included solar scientists, industry analysts, and industry CEOs to develop and confirm the demarcations among the three sizes of change. Table 1 provides examples of the characteristics of each size of change for each solar PV technology.

We operationalized *major technology change*, or competence-destroying changes, as a change between technology categories. While these categories rely on the same basic physics of converting solar energy to other forms of energy, they are differentiated by differences in chemistry (i.e., change between periodic elements used in the solar cell) and scale (e.g., change between high and low concentrators) (Bradford, 2006; Lynn, 2010). We categorized changes between categories as 'major' competence-destroying changes because they require creation of substantial new knowledge. They also require unusually high levels of substitution of knowledge and resources: entire scientific teams may be replaced, new intellectual property must be codified, and new manufacturing processes must be developed. In the words of one entrepreneur in the study, these major changes are 'huge, massive.' As an example, a firm shifting from making plastic solar cells based on titanium dioxide to CIGS, a four-layer thin film composed of copper indium gallium di-selenide, must abandon its existing patents and processes to develop a very different solar cell requiring completely new manufacturing processes and often requiring new scientists and engineers.

Moderate technology change is a mix of competence-destroying and enhancing elements. We measure this by a significant change *within* industry technology categories. Because these changes involve changes to chemistry or scale within a technology category, they still represent a significant reformulation of the technology and, as a result, often require development of skills, knowledge, processes, and products while still using some prior resources. For example, a firm pursuing a high-concentration solar module that shifts from an architecture that concentrates light at 500x to 800x is making a significant change to the product and to the skills required to develop the technology, but not a change between categories. Our panel of experts described these changes as difficult and time consuming, but not as significant as a change between categories.

Finally, we measure *minor technology change*, or competence-enhancing change, as a modest modification to format or application of the technology. In

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these technical changes, the firm makes modifications to its technology that require little disruption. Examples include adding barrier films, making small changes to the size of a solar cell, and making slight modifications to the technology to apply it in a related market. Although this type of change does require the firm to make alterations such as in manufacturing, it is only a minor change in the format of the cell that reinforces or extends existing capabilities.

Independent variables

Consistent with prior research, we use the backgrounds of the CEO and the CEO's direct reports (i.e., TMT) to measure our independent variables. We began by gathering data on these individuals using a method established by Beckman, Burton, and O'Reilly (2007). We gathered biographies for these executives from venture documents (Web sites, funding documentation, business plans, etc.) and augmented them with data from biographical sources (such as LinkedIn and Zoominfo) and, in cases of missing data, phone calls or emails requesting resumes (fewer than 10 percent of cases). We tracked changes in the CEO and TMT members quarterly. Next, since we are interested in the effect of industry experience on technology change, particularly deep industry experience, we categorized each individual based on whether his/her primary work experience occurred inside or outside the solar industry. We then created an aggregate categorical measure of the three different types of teams discussed in the hypotheses (domain insider, domain outsider, complementary). In creating the measure, we treated the CEO as a single individual and the TMT as the CEO's direct reports. We developed several alternative measures as robustness checks, including a percentage measure of the team domain experience, and these replicate the reported results.

We measure *intra-domain team* as a categorical measure equaling '1' when the CEO and 50 percent or more of the TMT are domain insiders, and '0' otherwise. Similarly, we measure *extra-domain team* as a categorical measure equaling '1' when the CEO and greater than 50 percent of the TMT are domain outsiders and '0' otherwise. We measure *complementary team* as a categorical measure that equals '1' when teams are complementary combinations (all cases where teams are neither extra-domain nor intra-domain teams) and '0' otherwise. We focus on complementarity between the CEO and the TMT because prior literature has emphasized the unique role of the CEO in information processing within teams (Eisenhardt, 1989b; Janis, 1972).

Controls

First, we use fixed effects for *technology category* to control for differences in technology categories that might influence the frequency or scale of technical change. We adjust this measure quarterly. Second, because the pace and range of technical fermentation intensified beginning in 2000, we control for the post-2000 time period.[3] Financial resources may influence the ability of the venture to change. Accordingly, we control for *financial resources*, measured as the log of the cumulative financial capital from professional investors received by the venture prior to the focal technical change, adjusted for inflation (PPI). We adjust this measure quarterly. Finally, we also tested many other potential control variables that are commonly used in the TMT literature and have been found to influence performance, including size (Carpenter *et al*., 2004), average work experience, functional heterogeneity, tenure, tenure heterogeneity, and CEO turnover. We also tested for firm size, nonlinear effects of background (quadratic), annual time controls, and information availability. These controls were not statistically significant and did not materially alter the results. Thus, we did not include them in the final, parsimonious model.

Statistical analyses

Because the dependent variable is a technology change event, we use an event history analysis to capture the full effects of our longitudinal data on dichotomous change. Thus, we use time-varying covariates, while also controlling for time dependence. Specifically, we employ a parametric analysis with a log-logistic distribution, a class of accelerated failure time (AFT) models that has gained broad acceptance because it has the attractive features of being robust to omitted covariates and the choice of hazard distribution (Keiding, Andersen, and Klein, 1997; Lambert *et al*., 2004).[4] We validated the

[3] To ensure the robustness of results, we also tested other breakpoints to capture this inflection point, obtaining similar results.

[4] The reader should note that, although hazard models and AFT models share similar underlying logic (Kleinbaum *et al*., 2005), an AFT model parameterizes 'time to an event' rather than 'hazard of an event,' consequently, in our results, the hypoth-

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appropriateness of the log-logistic distribution using Akaike's information criteria (Box-Steffensmeier, 2004) and standard graphing techniques (Blossfeld, Golsch, and Rohwer, 2007; Cleves *et al*., 2010; Kleinbaum and Klein, 2005). We also reproduced the results using alternate distribution assumptions, including Cox models (Cox, 1972; Kalbfleisch and Prentice, 2002). These alternatives replicated our results, but with less fit and efficiency than log-logistic.

Because ventures can experience multiple change events, we employ a multi-event methodology, common in fields studying recurring events such as international entry or medical incidents (Box-Steffensmeier, 2004; Cook and Lawless, 2007). To correct for nonindependence between recurring events, we use the standard Andersen-Gill variance-covariance matrix adjustment for the maximum partial likelihood estimate to generate robust estimators (Anderson and Gill, 1982; Cook and Lawless, 2007; Lin and Wei, 1989), as well as frailty analysis as a robustness check. As an additional robustness check on event independence, we also replicated the results using a conditional risk variance correction by stratifying events into groups, while constraining parameters to a single estimate (Prentice, Williams, and Peterson, 1981). Finally, we measure time between events (gap time) rather than time since founding for successive events (Box-Steffensmeier, 2004; Greve, 2009).

RESULTS

Table 3 presents descriptive statistics and correlations. Among the population of 68 firms, there are 31 instances of major change, 82 of moderate change, and 50 of minor change. Table 4 summarizes the primary analysis of the effects of domain experience on time to technology change, testing each hypothesis separately on the different types of competence-enhancing versus competence destroying technology changes: major (competence destroying), moderate (mix of competence destroying and competence enhancing), and minor (competence enhancing). For each degree of change, the variables are tested independently in Models 2 through 4 and then together in the full Model 5, which requires that we drop one variable in Model 5 due to collinearity. We chose to drop the intra-domain team variable, which means that in Model 5, coefficients are compared against a baseline of a domain insider team. All coefficients should be interpreted as a multiplier on time to change, meaning a coefficient above one implies an increase in the time before a change, whereas a coefficient below one implies a decrease in time to change, or an increased hazard of change.[5]

Hypothesis 1 predicts that teams composed of domain insiders increase the likelihood of competence-enhancing technology change. For minor changes, there are no statistically significant differences between the three types of teams. Thus, all types of teams make minor changes at a statistically similar rate. These results fail to support Hypothesis 1. By comparison in the models for moderate and major change, domain insider teams actually decrease the likelihood of making changes with an element of competence destruction (reflected as an increase in time to change in Model 2 for major changes ($p < 0.02$) and moderate changes ($p < 0.01$)). Taken together, these results indicate that although teams composed of domain insiders are equally likely to make minor changes, they have a significant inertial effect on moderate and major changes. They do not support H1.

Hypothesis 2 predicts that teams composed of domain outsiders are more likely to make competence-destroying technology changes. H2 is supported for major changes—i.e., the coefficient for domain outsider teams is below one and statistically significant in Model 3 ($p < 0.01$), implying a decrease in time to change. Furthermore, in the full Model 5, which compares against the baseline of an intra-domain team, the coefficient for domain outsider teams is 0.19 ($p < 0.01$), implying that extra-domain teams decrease the time to a major change by 81 percent as compared to domain insider teams. This result suggests that for the most competence-destroying changes, domain outsiders have a substantial effect on increasing the likelihood of change, providing support for H2. Similarly, H2 is supported for moderate changes—i.e., the coefficient for domain outsider teams is also below one and significant in Model 3 ($p < 0.01$), implying a decrease in time to change. In the full Model 5, once again

esized increased likelihood of change (an increase of hazard) will be reflected as a decrease in time to change (time ratio coefficient value below one).

[5] Time ratio coefficients are exponentiated coefficients in an AFT model, just as hazard ratios are exponentiated coefficients in a hazard model. Henceforth in the article, every coefficient is reported as a time ratio coefficient but for rhetorical simplicity, we will refer to them as coefficients.

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Table 3. Correlation matrix

	Variable	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Major tech change	0.03	0.06	1															
2	Moderate tech change	0.08	0.09	0.17	1														
3	Minor tech change	0.05	0.09	–0.17	–0.06	1													
4	Expert team	0.16	0.35	–0.20	–0.32	–0.09	1												
5	Novel team	0.65	0.47	0.22	0.30	–0.13	–0.64	1											
6	Complementary team	0.19	0.36	–0.10	–0.08	0.25	–0.14	–0.67	1										
7	Prior financial resources	2.58	1.16	0.04	0.18	0.00	–0.22	0.07	0.12	1									
8	Post-2000 time period	0.94	0.16	0.11	0.23	0.01	–0.33	0.26	–0.02	–0.16	1								
9	Crystalline silicone	0.13	0.34	–0.14	–0.04	0.14	–0.10	–0.22	0.39	0.08	0.05	1							
10	Thin film (amorphous silicon)	0.15	0.36	0.23	–0.12	–0.18	–0.08	0.14	–0.11	0.04	–0.09	–0.17	1						
11	Thin film (cadmium telluride)	0.07	0.26	–0.13	–0.20	0.28	0.03	–0.02	0.01	0.15	–0.03	–0.11	–0.12	1					
12	Thin film (CIGS)	0.11	0.31	–0.06	0.08	–0.02	–0.08	–0.04	0.12	0.06	–0.05	–0.14	–0.13	–0.10	1				
13	Low power concentrator	0.16	0.36	–0.06	0.10	0.11	0.02	0.12	–0.18	–0.15	–0.17	–0.18	–0.19	–0.13	–0.16	1			
14	High power concentrator	0.13	0.33	0.13	0.19	0.08	0.07	0.11	–0.21	–0.10	0.13	–0.16	–0.17	–0.12	–0.15	–0.13	1		
15	Multi-junction cell	0.04	0.21	0.05	–0.11	–0.09	0.10	–0.14	0.09	–0.04	–0.11	–0.08	–0.09	–0.06	–0.08	–0.10	–0.09	1	
16	Organic/nano-modified	0.15	0.35	–0.01	0.00	–0.23	0.15	–0.13	0.03	–0.14	0.17	–0.16	–0.18	–0.11	–0.15	–0.19	–0.17	–0.09	1

Note: Table presents correlation of average measure values for each firm. N = 68 firms, 1,265 firm-quarter spells.

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Table 4. Effects on time to technology change (coefficient equals multiplier on time to change)

Major technical change	Model 1		Model 2		Model 3		Model 4		Model 5	
	Wald chi^2	24.1	Wald chi^2	41.4	Wald chi^2	35.7	Wald chi^2	21.7	Wald chi^2	35.7
Measure	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.
Intra-domain team			5.02	0.73**						
Extra-domain team					0.28	0.32***			0.19	0.70***
Complementary team							1.71	0.58	0.39	0.89
Prior financial resources	1.01	0.15	1.11	0.12	1.14	0.14	1.01	0.16	1.15	0.13
Post-2000 time period	0.39	0.85	0.70	0.73	0.68	0.66	0.38	0.85	0.75	0.69
Moderate technical change	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**	
	Wald chi^2	32.5	Wald chi^2	87.5	Wald chi^2	80.3	Wald chi^2	33.0	Wald chi^2	92.3
Measure	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig. T.R.	S.E.	Sig.	T.R. S.E.	Sig.
Intra-domain team			12.99	0.53***						
Extra-domain team					0.20	0.46***			0.08	0.50***
Complementary team							1.42	0.71	0.12	0.77*
Prior financial resources	0.92	0.12	1.03	0.10	1.04	0.09	0.92	0.13	1.05	0.09
Post-2000 time period	0.21	0.70**	0.34	0.64*	0.38	0.61	0.21	0.70**	0.38	0.62
Minor technical change	**Model 1**		**Model 2**		**Model 3**		**Model 4**		**Model 5**	
	Wald chi^2	98.9	Wald chi^2	97.8	Wald chi^2	95.0	Wald chi^2	96.5	Wald chi^2	94.7
Measure	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.
Intra-domain team			0.92	0.30						
Extra-domain team					1.14	0.30			1.12	0.32
Complementary team							0.87	0.46	0.95	0.48
Prior financial resources	1.23	0.07***	1.22	0.09**	1.22	0.08***	1.24	0.08***	1.22	0.09**
Post-2000 time period	0.91	0.37	0.90	0.36	0.87	0.35	0.89	0.36	0.87	0.35

Fixed effects model by technology category; *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.10$ based on one-sided t-tests; n = 68 firms, 31 unique events, 1,265 firm-quarter apells.
Fixed effects model by technology category; *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.10$ based on one-sided t-tests; n = 68 firms, 82 unique events, 1,265 firm-quarter spells.
Fixed effects model by technology category; *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.10$ based on one-sided t-tests; n = 68 firms, 50 unique events, 1,265 firm-quarter spells.
Note: Since the model estimates effects on time to technology change, increased chances of changes are reflected by a coefficient < 1.

Table 5. Effects of complementary teams on time to technology change (coefficient equals multiplier on time to change)

Major technical change	Model 1		Model 2		Model 3	
	Wald chi^2	24.1	Wald chi^2	212.0	Wald chi^2	212.0
Measure	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.
Intra-domain team (CEO & TMT)					6.22	0.70***
Comp: intra-domain CEO/extra-domain TMT			1266	1.16***	7831	1.18***
Comp: extra-domain CEO/intra-domain TMT			0.16	0.70***		
Extra-domain team (CEO & TMT)			0.20	0.64**	1.23	0.44
Financial capital	1.01	0.15	1.13	0.13	1.13	0.13
Post-2000	0.39	0.85	0.76	0.61	0.76	0.61
Moderate technical change	Model 1		Model 2		Model 3	
	Wald chi^2	32.5	Wald chi^2	93.3	Wald chi^2	93.3
Measure	T.R. S.E.	Sig.	T.R. S.E.	Sig.	T.R. S.E.	Sig.
Intra-domain team (CEO & TMT)					8.26	0.71***
Comp: intra-domain CEO/extra-domain TMT			0.13	0.92**	1.08	0.87
Comp: extra-domain CEO/intra-domain TMT			0.12	0.71***		
Extra-domain team (CEO & TMT)			0.08	0.53***	0.63	0.50
Financial capital	0.92	0.12	1.05	0.09	1.05	0.09
Post-2000	0.21	0.70**	0.38	0.64	0.38	0.64

Fixed effects model by technology category; *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.10$ based on one-sided t-tests; ; ^=directional support; n = 68 firms, 31 unique events, 1,265 firm-quarter spells.
Fixed effects model by technology category; *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.10$ based on one-sided t-tests; n = 68 firms, 82 unique events, 1,265 firm-quarter spells.
Note: Since the model estimates effects on time to technology change, increased chances of changes are reflected by a coefficient < 1.

comparing to a baseline of domain insiders, the coefficient for an extra-domain team is 0.08 ($p < 0.01$), implying that domain outsider teams decrease the time to a moderate change by 92 percent as compared to a domain insider team. Thus, these results support H2 for moderate and major changes such that domain outsider teams are more likely to make moderate and major changes than domain insider teams. As reported earlier, we do not find a statistically significant difference between the different teams for minor changes.

Hypothesis 3 predicts that complementary teams (i.e., intra-domain CEO/extra-domain TMT or extra-domain CEO/intra-domain TMT) increase the likelihood of technology change. Since all three types of teams are likely to make minor changes, the results do not support H3 for minor changes. In contrast, the results support H3 for moderate change. In the full Model 5 for moderate changes, which compares against a baseline of intra-domain teams, the coefficient for complementary teams has a value of 0.12 ($p < 0.07$), suggesting that a complementary team decreases the time to a moderate change by 88 percent compared to a team of domain insiders. This confirms H3 for moderate changes. Finally, we do not support H3 for major changes.

Given the limited support for H3, we conducted a *post hoc* analysis in which we distinguished two types of complementary teams: complementary teams with an intra-domain CEO and complementary teams with an extra-domain CEO. Although we hypothesized that either complementary combination would produce change, research on TMTs suggests a uniquely important role for the CEO in influencing his/her team because this leader often sets the focus of attention and priorities (Eisenhardt, 1989b; Janis, 1972; Ocasio, 1997). The supplementary analysis examines this possibility (Table 5) by employing the same parametric analysis and compares categorical measures for each type of team against a baseline team composed of domain insiders in Model 2 and a baseline complementary team in Model 3.

For moderate changes, both types of complementary teams, whether led by an intra-domain CEO or

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domain outsider, decrease time to change compared to an intra-domain team. Specifically, in Model 2, a complementary team led by an intra-domain CEO decreases the time to a moderate change by 87 percent ($p < 0.03$) compared to a team composed entirely of domain insiders. Similarly, in the same model, a complementary team led by a CEO from outside the domain decreases the time to a moderate change by 88 percent ($p < 0.01$) as compared to an all domain team. As a final point of observation, in Model 3, which compares against a baseline complementary team led by a domain outsider CEO, there are no significant differences between the two types of complementary teams or the team composed entirely of domain outsiders. In other words, all these teams increase moderate changes, which are composed of both competence-enhancing and competence-destroying, elements at a similar rate.

In contrast, for major changes, in both Models 2 and 3, the coefficients for the two types of complementary teams point in opposite directions. In Model 2, complementary teams led by an intra-domain CEO increase time to change ($p < 0.01$),[6] whereas complementary teams led by an extra-domain CEO decrease time to change ($p < 0.01$). For the sake of comparison, in Model 2, complementary teams led by a domain outsider CEO decrease the time to change by 84 percent as compared to a team composed entirely of domain insiders. Taken together, these results indicate that both types of complementary teams are more likely to make moderate changes than all domain teams and so confirm H3 for moderate change. In contrast, only complementary teams led by extra-domain CEOs make major changes and so confirm H3 only for outsider CEO, complementary teams.

DISCUSSION

The foundations of established businesses are often laid early in a firm's life when executives search for an attractive opportunity. In this search process, the executives guiding a venture play a crucial role in the recognition of information signaling the need to change. On the one hand, executives with deep domain experience, much like experts, may benefit from more robust problem structure perception, pattern recognition, and solution representation that allow them to recognize the need to change during their search. On the other hand, executives with experience outside the focal domain may bring novel framing, varied analogies, and lower affective commitment that allow them to recognize information signaling the need to change. Therefore, we explore how the backgrounds of venture executives affect the likelihood of change, asking: which venture executives—domain insiders or domain outsiders—are more likely to make technology changes? We focus on competence-enhancing and competence-destroying technology changes because of their importance to many high-potential ventures as they search for viable opportunities. We test this question using an event history on a unique data set capturing the full longitudinal history of all changes over time among the population of U.S. solar photovoltaic manufacturing ventures from 1992 to 2007.

We find that domain outsiders play a critical role in the likelihood of making significant technology change. Specifically, we find that teams composed of domain outsiders were just as likely to make minor, competence-enhancing changes and more likely to make moderate changes than intra-domain teams. Furthermore, teams composed of domain outsiders were uniquely likely to make major, competence-destroying technology changes. By contrast, many complementary teams that mingle insiders and outsiders are likely to make minor and moderate changes, but are unlikely to make major changes. Finally, teams composed of domain insiders are the most inertial. They are equally likely to make minor changes, but unlikely to make moderate and major ones. Overall, we believe these results make a contribution by highlighting the critical role of executive background on the decision to change and by suggesting that novel framing, introduced by domain outsiders either at the CEO or TMT level, potentially increases the cognitive flexibility of the team and the likelihood of change.

Implications for organizational change

Our results contribute insights to the organization change, strategy, and entrepreneurship literatures.

[6] Note the time ratio for complementary teams led by an intra-domain CEO is an extreme value. The statistical model generates an extreme value because this particular team combination never produces a major change, making it difficult to estimate a coefficient efficiently because no events occur, thus skewing the estimated coefficient toward infinity. We have investigated this outcome using multiple models and specifications and the reported results for each team configuration are always robust and significant. A simpler explanation may be that rarely do intra-domain CEOs hire domain outsiders into their TMT, so there are few teams of this type and these teams tend to be fairly inertial.

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Prior research notes the struggles of established firms to engage in competence-destroying technology change (Christensen and Bower, 1996; Gilbert, 2005; Henderson and Clark, 1990; Tripsas, 1997). Other research indicates the importance of making small but continuous changes (Brown and Eisenhardt, 1997; Rindova and Kotha, 2001). Yet, both of these streams of work neglect the full, broader range of changes (competence enhancing, destroying, and mixed changes) that is likely to be relevant for firms seeking opportunities in nascent markets. They also ignore the types of executives and teams that make these changes beyond the drastic action of sweeping out the executive team (Tushman and Rosenkopf, 1996). By contrast, we expand the organization change discussion by examining, across an industry population, a broader range of technology change than either competence-destroying or competence-enhancing change alone, and we do so using data capturing multiple changes over time. Employing a rich longitudinal data set within a very appropriate industry, we also add a quantitative robustness that goes beyond the case studies that are a mainstay of much of the prior research. We find that when firms make very large technology changes, extra-domain experience in teams and CEOs is key to making such changes. Furthermore, extra-domain experience within the top management team enhances a firm's propensity to make moderate changes. Finally, we find that technology changes undertaken by intra-domain teams tend to be smaller, competence-enhancing changes. Providing quantitative evidence of the breadth of change and the variety of change sets the stage to move beyond the discussion of inertia to one of strategic agility: why do some firms change and what are the outcomes? Moreover, our results provide some potential insight into complexity and evolutionary theories by demonstrating how the backgrounds of executives affect the distribution of minor (incremental), moderate, and major (long jump) changes relevant to successful firm evolution and growth (Brown and Eisenhardt, 1998; Levinthal, 1997).

Finally, although the change literature has focused primarily on change in established firms, discussing the challenges of making such changes, our research highlights the potential importance and frequency of change for new firms in search of opportunities. Although we do not test the relationship between change and performance, prior research suggests that for ventures, change can be critical to opportunity capture and survival (Dencker, Gruber, and Shah, 2009). In many situations (such as dynamic environments or eras of ferment) or for many actors (such as new ventures or firms moving to new markets), the ability to change may be an important component of firm growth and performance. Representative of these challenges, the solar PV industry has been characterized by a high amount of environmental dynamism to which firms must adjust: as one solar CEO publicly stated, 'the solar industry has changed so much it's almost enough to make you want to cry' (Woody, 2010: B1). Furthermore, the internal process of developing PV technology tends to be fraught with surprises that require the ability to change. In support of this view, our qualitative work highlighted the importance of change for firms in the solar industry, especially for teams composed of domain insiders. A particularly revealing comparison contrasts two firms. One venture, founded in 2001 and led by a team of renowned experts, spent six years developing its unique CIGS solar modules, making only minor changes, but slowly falling behind competitors. It finally exited through an informal asset sale. By contrast, another venture founded the same year by a team of domain outsiders spent two years developing an organic solar cell before realizing their solar cell would take more than a decade to commercialize. Venture executives quickly changed to developing CIGS solar cells, making several more moderate and minor technology changes along the way. Even with a two-year disadvantage, these executives were able to morph to the finish line of commercialization well before their eminent competitor that failed to change. Similar cases abound that highlight how domain insiders persist too long pursuing their deeply held beliefs while more nimble domain outsiders, who quickly recognize when changes need to be made, pull ahead in the development process. While in this article we limited the discussion to who makes changes, in future work we expect to more robustly explore how these changes impact performance.

Toward the psychological foundations of strategy

Our research also provides motivation to explore further the psychological foundations of strategy, particularly the emerging concept of cognitive flexibility. To illustrate, in the case above we told the story of an extra-domain team changing from an organic solar cell to CIGS solar cells while beating their competitors to market. In speaking of the

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reasons why they made such changes, the CEO highlighted largely cognitive reasons, or how the ability to 'see' things differently, allowed them to advance more quickly: 'many of our most significant advances and breakthroughs came from intensely trying new things often diametrically counter to any beliefs' (Fehrenbacher, 2007). By contrast, many executives in the industry said domain insiders often held a more rigid view of the world. For example, one CEO stated that in hiring his CTO, 'technically he is very good and he's not coming out of the PV industry which I think in this case was positive. He doesn't come with a predetermined view of things.' Ultimately, when discussing the adaptations they did make, executives highlighted cognitive reasons for making changes and they highlighted cognitive reasons why some executives resisted change. In the words of another domain outsider CEO with several successful exits: 'the thing that scares me most is someone who is convinced they are right, because they will never change,' whereas 'I knew that I didn't know the right answer, so I was willing to change.' Given prior work on the psychological foundations of strategy and these qualitative observations, the quantitative evidence in this article regarding the effects of intra- and extra-domain experience on technology change opens up new avenues in the study of how executive backgrounds shape cognition, framing, and strategic choice. While early work on framing argued that decision maker background plays an important role in framing of decisions such as change (Kahneman and Tversky, 1979; Tversky and Kahneman, 1981), our work provides validation of how these backgrounds affect change. Although we suggest that decision makers' backgrounds affect change because the breadth of their experiences increases their cognitive flexibility, future work could isolate and document the construct of cognitive flexibility and its operation at multiple levels of organization (Furr, 2009). Such work may be foundational to our understanding of other core constructs, such as dynamic capability, where the management of the resource portfolio, as highlighted in this article, is significantly affected by executive background. Cognitive flexibility may play a fundamental role in seeding dynamic capability (Bingham *et al*., 2007; Eisenhardt *et al*., 2010), integrating the information needed to develop dynamic capability (Zollo and Winter, 2002), and recognizing when to activate a dynamic capability (Tripsas and Gavetti, 2000)—all topics that deserve further exploration.

Toward a sociological view of the top management team

Finally, our finding that CEOs with prior experience in other domains are the linchpins of change contributes to the top management team (TMT) literature and the emerging sociological view of the top management team (Beckman and Burton, 2011). Prior research emphasizes the role of top management teams. Indeed, larger teams improve the growth (Eisenhardt and Schoonhoven, 1990), survival, and access to resources (Eisenhardt and Schoonhoven, 1996; Stuart, Hoang, and Hybels, 1999) of ventures. Additional research points to the value of diverse teams with broad functional experience and rich industry experience (Eisenhardt and Schoonhoven, 1990). Whereas these views often treat the TMT as an aggregation of individuals, by contrast, we treat the TMT as a distinct social unit with attention to the structure of the TMT. We find that social structures matter to the operation of the TMT (Beckman and Burton, 2008; Beckman *et al*., 2007), and we demonstrate how extra-domain CEOs who bring a fresh industry perspective are essential for making large technical changes, regardless of whether their team is composed of industry insiders or outsiders. By contrast, CEOs with domain expertise emerge as a primary source of inertia in the search for opportunities. Therefore, while the TMT may be generally important to the success and activities of ventures, CEOs and the structure of the team play a unique role in orchestrating change, particularly for changes beyond minor, competence-enhancing changes.

In conclusion, this work addresses the question of how executive backgrounds affect the likelihood of change during the search for opportunities. We argued that while domain insiders bring many potential strengths beyond domain knowledge, including potentially greater problem structure recognition, pattern recognition, and solution representation, these individuals actually have an inertial effect on the search process leading the firm to focus on smaller, competence-enhancing changes. Moreover, such intra-domain teams struggle to recognize and execute more significant, competence-destroying changes. By contrast, domain outsiders—particularly CEOs—who bring novel framing increase the ability of the firm to make more significant changes in the search for new opportunities. This work provides direction for further investigation of organization change early in firm life, the

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psychological foundations of strategy, and the sociological view of the top management team.

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REFERENCES

Abernathy W, Clark K. 1985. Innovation: mapping the winds of creative destruction. *Research Policy* **14**: 3–22.

Adner R, Helfat CE. 2003. Corporate effects and dynamic managerial capabilities. *Strategic Management Journal* **24**(10): 1011–1025.

Anderson JR. 2000. *Learning and Memory: An Integrated Approach*. Wiley: New York.

Anderson PK, Gill RD. 1982. Cox's regression model for counting processes: a large sample study. *The Annals of Statistics* **10**: 1100–1120.

Baron RA, Ensley MD. 2006. Opportunity recognition as the detection of meaningful patterns: evidence from comparisons of novice and experienced entrepreneurs. *Management Science* **52**(9): 1331–1344.

Barr PS, Stimpert JL, Huff AS. 1992. Cognitive change, strategic action, and organizational renewal. *Strategic Management Journal*, Summer Special Issue **13**: 15–36.

Bartunek JM. 1984. Changing interpretive schemes and organizational restructuring: the example of a religious order. *Administrative Science Quarterly* **29**(3): 355–372.

Bassok M. 1990. Transfer of domain-specific problem-solving procedures. *Journal of Experimental Psychology: Learning, Memory, and Cognition* **16**(3): 522–533.

Bassok M, Holyoak KJ. 1989. Interdomain transfer between isomorphic topics in algebra and physics. *Journal of Experimental Psychology* **15**: 153–166.

Beckman CM. 2006. The influence of founding team company affiliations on firm behavior. *Academy of Management Journal* **49**(4): 741–758.

Beckman CM, Burton MD. 2008. Founding the future: path dependence in the evolution of top management teams from founding to IPO. *Organization Science* **19**(1): 3–24.

Beckman CM, Burton MD. 2011. Bringing organizational demography back in: time, change, and structure in top management team research. In *Handbook of Top Management Team Research*, Carpenter MA (ed). Edward Elgar: Northamptom, MA; 49–70.

Beckman CM, Burton MD, O'Reilly C. 2007. Early teams: the impact of team demography on VC financing and going public. *Journal of Business Venturing* **22**(2): 147–173.

Benner MJ, Tushman M. 2003. Exploitation, exploration, and process management: the productivity dilemma revisited. *Academy of Management Review* **28**: 238–256.

Bingham C, Eisenhardt KM. 2011. Rational heuristics: the 'simple rules' strategists explicitly learn from their process experiences. *Strategic Management Journal* **32**(13): 1437–1464.

Bingham C, Eisenhardt KM, Furr N. 2007. What makes a process a capability? Heuristics, strategy, and effective capture of opportunities. *Strategic Entrepreneurship Journal* **1**(1): 27–47.

Blossfeld H-P, Golsch K, Rohwer G. 2007. *Event History Analysis with Stata*. Lawrence Erlbaum Associates: New York.

Box-Steffensmeier J. 2004. *Event History Modeling: A Guide for Social Scientists*. Cambridge University Press: West Nyack, NY.

Bradford T. 2006. *Solar Revolution: The Economic Transformation of the Global Energy Industry*. MIT Press: Cambridge, MA.

Brown SL, Eisenhardt KM. 1997. The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Administrative Science Quarterly* **42**: 1–34.

Brown SL, Eisenhardt KM. 1998. *Competing on the Edge: Strategy as Structured Chaos*. Harvard Business School Press: Boston, MA.

Carpenter MA, Geletkanycz MA, Sanders WG. 2004. Upper echelons research revisited: antecedents, elements, and consequences of top management team composition. *Journal of Managment* **30**(6): 749–778.

Chase WG, Simon HA. 1973. Perception in chess. *Cognitive Psychology* **4**(1): 55–81.

Chi MTH, Glaser R, Farr M. 1988. *The Nature of Expertise*. Lawrence Erlbaum Associates: Hillsdale, NJ.

Chi MTH, Glaser R, Rees E. 1982. Expertise in problem solving. In *Advances in the Psychology of Human Intelligence* (Vol. 1), Sternberg RJ (ed). Lawrence Erlbaum Associates: Hillsdale, NJ; 7–75.

Christensen C, Bower JL. 1996. Customer power, strategic investment, and the failure of leading firms. *Strategic Management Journal* **17**(3): 197–218.

Cleves M, Gutierrez RG, Gould W, Marchenko YV. 2010. *An Introduction to Survival Analysis Using Stata* (3rd edn). Stata Press: College Station, TX.

Cook RJ, Lawless JF. 2007. *The Statistical Analysis of Recurrent Events*. Springer: New York.

Cox DR. 1972. Regression models and life tables. *Journal of the Royal Statistical Society* **34**: 187–200.

Dane E. 2010. Reconsidering the trade-off between expertise and flexibility: a cognitive entrenchment perspective. *Academy of Management Review* **35**(4): 579–603.

Dencker JC, Gruber M, Shah SK. 2009. Pre-entry knowledge, learning, and the survival of new firms. *Organization Science* **20**(3): 516–537.

Dorf RC, Byers TH. 2008. *Technology Ventures: From Idea to Enterprise*. McGraw-Hill: New York.

Dutton JE, Dukerich JM. 1991. Keeping an eye on the mirror: image and identity in organizational adaptation. *Academy of Management Journal* **34**(3): 517–554.

Edmondson AC, Bohmer RM, Pisano GP. 2001. Disrupted routines: team learning and new technology implementation in hospitals. *Administrative Science Quarterly* **46**: 685–716.

Eggers JP, Kaplan S. 2009. Cognition and renewal: comparing CEO and organizational effects on incumbent adaptation to technical change. *Organization Science* **20**(2): 461–477.

Eisenhardt KM. 1989a. Building theories from case study research. *Academy of Management Review* **14**: 532–550.

Eisenhardt KM. 1989b. Making fast strategic decisions in high-velocity environments. *Academy of Management Journal* **32**(3): 543–576.

Eisenhardt KM, Furr N, Bingham C. 2010. Microfoundations of performance: balancing efficiency and flexibility in dynamic environments. *Organization Science* **21**(6): 1263–1273.

Eisenhardt KM, Graebner ME. 2007. Theory building from cases: opportunities and challenges. *Academy of Management Journal* **50**(1): 25–32.

Eisenhardt KM, Santos F. 2006. Knowledge-based view: a new theory of strategy? In *Handbook of Strategy and Management*, Pettigrew AM, Thomas H, Whittington R (eds). SAGE Publications: Thousand Oaks, CA; 139–164.

Eisenhardt KM, Schoonhoven CB. 1990. Organizational growth: linking founding team, strategy, environment, and growth among U.S. semiconductor ventures. *Administrative Science Quarterly* **35**(3): 504–529.

Eisenhardt KM, Schoonhoven CB. 1996. Resource-based view of strategic alliance formation: strategic and social effects in entrepreneurial firms. *Organization Science* **7**(2): 136–150.

Ericsson KA. 2006. *The Cambridge Handbook of Expertise and Expert Performance*. Cambridge University Press: New York.

Ericsson KA, Charness N. 1994. Expert performance: its structure and acquisition. *American Psychologist* **49**: 725–747.

Fehrenbacher K. 2007. 10 questions for Nanosolar CEO Martin Roscheisen. Available at: http://gigaom.com/cleantech/10-questions-for-nanosolar-ceo-martin-roscheisen/ (accessed 15 July 2011).

Fiske ST, Taylor SE. 1991. *Social Cognition*. McGraw-Hill: New York.

Furr NR. 2009. Cognitive flexibility: the adaptive reality of concrete organization change. Unpublished PhD dissertation, Stanford University.

Galunic DC, Eisenhardt K. 2001. Architectural innovation and modular corporate forms. *Academy of Management Journal* **44**(6): 1229–1249.

Gavetti G. 2012. Toward a behavioral theory of strategy. *Organization Science* **23**(1): 267–285.

Gavetti G, Levinthal DA. 2000. Looking forward and looking backward: cognitive and experiential search. *Administrative Science Quarterly* **45**: 113–137.

Gavetti G, Levinthal DA, Rivkin JW. 2005. Strategy making in novel and complex worlds: the power of analogy. *Strategic Management Journal* **26**(8): 691–712.

Gilbert C. 2005. Unbundling the structure of inertia: resource versus routine rigidity. *Academy of Management Journal* **48**(5): 741–763.

Gilbert C. 2006. Change in the presence of residual fit: can competing frames coexist? *Organization Science* **17**(1): 150–167.

Gitomer DH. 1988. Individual differences in technical troubleshooting. *Human Performance* **1**: 111–131.

Grant RM. 1996a. Prospering in dynamically-competitive environments: organizational capability as knowledge integration. *Organization Science* **7**(4): 375–387.

Grant RM. 1996b. Toward a knowledge-based theory of the firm. *Strategic Management Journal*, Winter Special Issue **17**: 109–122.

Grégoire DA, Barr PS, Shepherd DA. 2010. Cognitive processes of opportunity recognition: the role of structural alignment. *Organization Science* **21**(2): 413–431.

Greve HR. 2009. Now is the time: routines, attention, and interdependence in organizational change. Paper presented at the annual meeting of the Academy of Management: Chicago, IL.

Gruber M, MacMillan IC, Thompson JD. 2010. From minds to markets: how human capital endowments shape market opportunity identification of technology start-ups. Available at: http://jom.sagepub.com/content/early/2010/11/19/0149206310386228 (accessed 22 July 2011).

Hambrick DC. 2007. Upper echelons theory: an update. *Academy of Management Review* **32**: 334–343.

Hargadon A, Sutton RI. 1997. Technology brokering and innovation in a product development firm. *Administrative Science Quarterly* **42**(4): 716–749.

Hawkins RD, Kandel ER, Siegelbaum SA. 1993. Learning to modulate transmitter release: themes and variations in synaptic plasticity. *Annual Review of Neuroscience* **16**: 625–665.

Helfat CE. 1997. Know-how and asset complementarity and dynamic capability accumulation: the case of R&D. *Strategic Management Journal* **18**(5): 339–360.

Henderson RM, Clark KB. 1990. Architectural innovation: the reconfiguration of existing product technologies and

DOI: 10.1002/sej

the failure of established firms. *Administrative Science Quarterly* **35**: 9–30.

Hinds PJ, Patterson M, Pfeffer J. 2001. Bothered by abstraction: the effect of expertise on knowledge transfer and subsequent novice performance. *Journal of Applied Psychology* **86**(6): 1232–1243.

Holbrook D, Cohen WM, Hounshell DA, Klepper S. 2000. The nature, sources, and consequences of firm differences in early history of the semiconductor industry. *Strategic Management Journal* **21**(10/11): 1017–1041.

Huy QN. 2002. Emotional balancing of organizational continuity and radical change: the contribution of middle managers. *Administrative Science Quarterly* **47**(1): 31–69.

Janis I. 1972. *Victims of Groupthink*. Houghton Mifflin: Boston, MA.

Jeppesen LB, Lakhani KR. 2010. Marginality and problem-solving effectiveness in broadcast search. *Organization Science* **21**(5): 1016–1033.

Kador J. 2002. *Charles Schwab: How One Company Beat Wall Street and Reinvented the Brokerage Industry*. John Wiley and Sons: Hoboken, NJ.

Kahneman D, Tversky A. 1979. Prospect theory: an analysis of decision under risk. *Econometrica* **47**(2): 263–291.

Kahneman D, Tversky A. 1984. Choice, values, and frames. *American Psychology* **39**(4): 341–350.

Kalbfleisch JD, Prentice RL. 2002. *The Statistical Analysis of Failure Time Data* (2nd edn). Wiley-Interscience: Hoboken, NJ.

Kaplan S. 2008. Cognition, capabilities, and incentives: assessing firm response to the fiber-optic revolution. *Academy of Management Journal* **51**(4): 672–695.

Kaplan S, Tripsas M. 2008. Thinking about technology: applying a cognitive lens to technical change. *Research Policy* **37**: 790–805.

Katila R. 2004. Existing knowledge as a source of value. Working paper, Stanford University.

Keiding N, Andersen PK, Klein JP. 1997. The role of frailty models and accelerated failure time models in describing heterogeneity due to omitted covariates. *Statistics in Medicine* **16**(2): 215–224.

Kleinbaum DG, Klein M. 2005. *Survival Analysis* (2nd edn). Springer: New York.

Knowlton B. 1997. Declarative and nondeclarative knowledge: insights from cognitive neuroscience. In *Knowledge, Concepts, and Categories*, Lambert K, Shanks D (eds). MIT Press: Cambridge, MA; 215–246.

Lambert P, Collett D, Kimber A, Johnson R. 2004. Parametric accelerated failure time models with random effects and an application to kidney transplant survival. *Statistics in Medicine* **23**(20): 3177–3192.

Levinthal D. 1997. Adaptation on rugged landscapes. *Management Science* **43**(7): 934–950.

Lin DY, Wei LJ. 1989. The robust inference for the Cox proportional hazards model. *Journal of the American Statistical Association* **84**: 1074–1078.

Lynn PA. 2010. *Electricity from Sunlight: An Introduction to Photovoltaics*. John Wiley & Sons: West Sussex, U.K.

McEvily SK, Chakravarthy B. 2002. The persistence of knowledge-based advantage: an empirical test for product performance and technological knowledge. *Strategic Management Journal* **23**(4): 285–305.

Mehta S. 2010. *PV Technology, Production, and Cost Outlook: 2010–2015*. Greentech Media: Cambridge, MA.

Newell A, Simon H. 1972. *Human Problem Solving*. Prentice Hall: Englewood Cliffs, NJ.

North JS, Williams AM, Hodges N, Ward P, Ericsson KA. 2009. Perceiving patterns in dynamic action sequences: investigating the processes underpinning stimulus recognition and anticipation skill. *Applied Cognitive Psychology* **23**(6): 878–894.

Ocasio W. 1997. Towards an attention-based view of the firm. *Strategic Management Journal*, Summer Special Issue **18**: 187–206.

Okhuysen GA. 2001. Structuring change: familiarity and formal interventions in problem-solving groups. *Academy of Management Journal* **44**(4): 794–808.

Okhuysen GA, Eisenhardt KM. 2002. Integrating knowledge in groups: how formal interventions enable flexibility. *Organization Science* **13**(4): 370–386.

Plous S. 1993. *The Psychology of Judgment and Decision Making*. McGraw-Hill: New York.

Prentice RL, Williams BJ, Peterson AV. 1981. On the regression analysis of multivariate time failure data. *Biometrika* **68**: 373–379.

Reeves LM, Weisberg RW. 1994. The role of content and abstract information in analogical transfer. *Psychological Bulletin* **115**(3): 381–400.

Rindova V, Kotha S. 2001. Continuous morphing: competing through dynamic capabilities, form, and function. *Academy of Management Journal* **44**(6): 1263–1280.

Rosenbloom RS. 2000. Leadership, capabilities, and technological change: the transformation of NCR in the electronic era. *Strategic Management Journal* **21**(10/11): 1083–1103.

Shah SK, Tripsas M. 2007. The accidental entrepreneur: the emergent and collective process of user entrepreneurship. *Strategic Entrepreneurship Journal* **1**(1/2): 123–140.

Shane S. 2000. Prior knowledge and the discovery of entrepreneurial opportunities. *Organization Science* **11**(4): 448–469.

Shepherd GM. 1991. *Foundations of the Neuron Doctrine*. Oxford University Press: New York.

Smith SM, Ward TB, Finke RA (eds). 2009. *The Creative Cognition Approach*. MIT Press: Cambridge, MA.

Smith WK, Tushman ML. 2005. Managing strategic contradictions: a top management model for managing innovation streams. *Organization Science* **16**(5): 522–536.

Staw BM. 1976. Knee-deep in the big muddy: a study of escalating commitment to a chosen course of action. *Organizational Behavior & Human Decision Processes* **16**(1): 27–44.

DOI: 10.1002/sej

Staw BM. 1981. The escalation of commitment to a chosen course of action. *Academy of Management Review* **6**: 577–587.

Stuart TE, Hoang H, Hybels RC. 1999. Interorganizational endorsements and the performance of entrepreneurial ventures. *Administrative Science Quarterly* **44**: 315–349.

Sull DN, Tedlow RS, Rosenbloom RS. 1997. Managerial commitments and technological change in the U.S. tire industry. *Industrial & Corporate Change* **6**(2): 461–501.

Taylor A, Greve HR. 2006. Superman or the fantastic four? Knowledge combination and experience in innovative teams. *Academy of Management Journal* **49**(4): 723–740.

Thomke S, Kuemmerle W. 2002. Asset accumulation, interdependence, and technological change: evidence from pharmaceutical drug discovery. *Strategic Management Journal* **23**(7): 619–635.

Thompson JD. 1967. *Organizations in Action*. McGraw-Hill: New York.

Tripsas M. 1997. Unravelling the process of creative destruction: complementary assets and incumbent survival in the typesetter industry. *Strategic Management Journal*, Summer Special Issue **18**: 119–142.

Tripsas M, Gavetti G. 2000. Capabilities, cognition, and inertia: evidence from digital imaging. *Strategic Management Journal* **21**(10/11): 1147–1161.

Tushman ML, Anderson P. 1986. Technological discontinuities and organizational environments. *Administrative Science Quarterly* **31**: 439–465.

Tushman ML, Rosenkopf L. 1996. Executive succession, strategic reorientation, and performance growth: a longitudinal study in the U.S. cement industry. *Management Science* **42**(7): 939–953.

Tversky A, Kahneman D. 1981. The framing of decisions and the psychology of choice. *Science* **211**: 453–458.

Vise D, Malseed M. 2006. *The Google Story: Inside the Hottest Business, Media, and Technology Success of Our Time*. Delta: New York.

Whittlesea BWA. 1997. The representation of general and particular knowledge. In *Knowledge, Concepts, and Categories*, Lambert K, Shanks D (eds). MIT Press: Cambridge, MA; 335–371.

Wiersema MF, Bantel KA. 1992. Top management team demography and corporate strategic change. *Academy of Management Journal* **35**(1): 91–121.

Wiersema MF, Bantel KA. 1993. Top managment team turnover as an adaptation mechanism: the role of the environment. *Strategic Management Journal* **14**(7): 485–504.

Woody T. 2010. Silicon Valley's solar innovators retool to catch up to China. *The New York Times*, 12 October: B1.

Zollo M, Winter SG. 2002. Deliberate learning and the evolution of dynamic capabilities. *Organization Science* **13**(3): 339–351.

DOI: 10.1002/sej