CAPABILITIES, TECHNOLOGIES, AND FIRM SURVIVAL DURING INDUSTRY SHAKEOUT: EVIDENCE FROM THE GLOBAL SOLAR PHOTOVOLTAIC INDUSTRY

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ABSTRACT

New industries are typically characterized by a period of emergence, shakeout and maturity. Prior explanations of firm exit during industry shakeout focus on either the role of choosing the technology that becomes the dominant design or of entrant's pre-entry capabilities. In this paper we bring together these disparate explanations and explore their joint effect on firm survival to create a more complete picture of industry evolution. We also consider distinct exit pathways, namely dissolution, which results in the death of the firm and its capabilities, and acquisition, which results in the termination of the firm but in the redeployment of its capabilities. Finally in a series of post-hoc analysis we explore the impact of related pre-entry capabilities and post-entry strategy change. The context for the study is the solar photovoltaic industry from 1978-2015. We find that technology choice and pre-entry capabilities are strong predictors of survival, acting jointly as complements to increase survival or independently as buffers against failure. Furthermore, many firms that exit are not dissolved, and diversifying entrants that enter with the dominant design technology are least likely to exit via dissolution. Overall, the findings from the study unpack the different facets of firms and their strategies, providing a more multi-faceted picture of firm survival in new industries.

Keywords: industry evolution, technology choice, shakeout, exit, capabilities

INTRODUCTION

The emergence of new industries and their subsequent evolution has been studied by management scholars for more than three decades. A stylized pattern that has been documented across a range of industries is that the initial period of an industry is characterized by an increasing rate of entry by both diversifying firms and new start-ups which is then followed by a period of shakeout when a large number of firms exit (Agarwal and Gort, 2002; Agarwal and Tripsas, 2011; Utterback and Suárez, 1993). In exploring the drivers of firm exit during shakeout, scholars have drawn on two distinct theoretical perspectives. Those taking an evolutionary economics perspective have considered the role of firms' pre-entry capabilities, explicitly focusing on the difference between diversifying entrants and new start-ups (Carroll *et al.*, 1996; Ganco and Agarwal, 2009; Khessina and Carroll, 2008; Klepper, 2002a; Klepper and Simons, 2000). Those taking a technology management perspective have considered the role of firms' entry choice, explicitly focusing on the type of technology firms' entered with and whether the technology became the dominant design (Abernathy and Utterback, 1978; Christensen, Suarez, and Utterback, 1998; Suarez and Utterback, 1995). However, while these modes of inquiry have generated valuable insights, they have remained isolated from each other, resulting in a relative lack of understanding regarding how firms' pre-entry capabilities and technology entry choice may interact and shape firms' ability to survive industry shakeout.

Furthermore, theoretical and empirical explorations of industry shakeout have focused solely on survival versus exit, with exit treated as a singular event associated with firm failure. This simplification, while useful and empirically tractable, has masked the fact that not all exits are equivalent. Although firms may exit via dissolution, which results in the dissolution of both the firm and its capabilities, alternatively, they may exit via acquisition, which results in the dissolution of the firm but the retention of its capabilities within the industry (Fortune and Mitchell, 2012). Examining different exit modes is important because during industry emergence firms build capabilities and whether a firm exits via dissolution or acquisition reveals the value that firms create from their capabilities. Indeed, even though most firms acquired during shakeouts are likely acquired at a discount to shareholder expectations, the fact that the firm was acquired rather than dissolved provides a signal about the value of the capabilities developed. Furthermore, those capabilities go on to influence the evolution of the industry, although within a different firm. Yet because prior work on industry evolution has treated dissolution and acquisition as equivalent exit events, we have limited understanding of how firms' pre-entry capabilities and technology entry choices are associated with the different modes of exit.

This paper attempts to explore how firms' pre-entry capabilities and technology entry choices jointly impact firm exit during industry shakeout as well as to unpack how these factors explain whether firms exit via dissolution or via acquisition. Specifically, we consider the effect of firms' pre-entry capabilities by distinguishing between diversifying entrants and start-ups, and we consider the effect of technology entry choices by distinguishing between firms entering with a technology that eventually becomes the dominant design and those entering with other alternative technologies. Finally, in a series of post hoc analysis, we examine how related pre-entry capabilities impact the likelihood of acquisition and how firms that are disadvantaged because of their technology entry choice or lack of pre-entry capabilities adapt their strategy over time in order to survive in the new industry.

We study these questions in the global solar photovoltaic (PV) industry from the late 1970s through 2015. The solar PV industry has become one of the major pillars of the renewable energy sector with annual revenues in the billions of dollars and expectations that it will play an ongoing role in the energy future of world as the cost of solar PV reaches grid parity (Bradford, 2006; Breyer and Gerlach, 2013). The industry provides an ideal setting in which to observe the impact of pre-entry organizational capabilities and technology choice on firm outcomes during shakeout. During the study period, we observe entrants with differing pre-entry capabilities—diversifying entrants with pre-existing organizational capabilities and start-up entrants lacking such capabilities—choose between two distinct technology groups—crystalline silicon and non-crystalline silicon—in a competition for dominance characteristic of many new industries. Furthermore we observe the outcomes of these choices as crystalline silicon emerges as the dominant design and an industry shakeout ensues with a peak of firm exits and an ensuing industry stabilization. Because the shakeout has occurred recently we can observe the details of firm exit, allowing us to carefully categorize firm exit into dissolution or acquisition and to observe how firms' pre-entry capabilities and technology choices affect the different types of exit outcomes.

The findings support the observations of prior literature that firms who enter with the technology that becomes the dominant design or who possess pre-entry organizational capabilities are less likely to exit during shakeout. But beyond prior findings, we find that these factors have important joint effects on likelihood of exit—acting as complements in some circumstances and as buffers in other circumstances, underscoring the importance of their mutual consideration in predicting the full range of firm outcomes during industry evolution. In the analysis of exit modes, we also find evidence for the impact of the joint consideration of these factors on the likelihood of dissolution relative to acquisition. Finally in a post hoc analysis, we observed that firms with related capabilities retained value that made them attractive acquisitions, even when they entered with the technology which did not evolve to become the dominant design. Furthermore, contrary to the typical evolution of an industry towards disaggregation (Helfat, 2015; Stigler, 1951), we observed a large number of firms integrating downstream in the solar PV vertical chain after entry, shifting their business model from solely manufacturing and selling modules to also include designing and installing solar PV systems for the end-users. While a large proportion of firms integrated downstream over time, those firms with liabilities, namely those that entered with the technology that did not become the dominant design or that lacked pre-entry capabilities (start-ups) appear to have moved downstream in greater proportions relative to the more advantaged firms. Furthermore, downstream integration was correlated with lower exit rates.

These findings provide a more complete picture of industry evolution and shakeout by going beyond the winners based on a predominant dimension considered in the extant literature streams, to explaining outcomes for firms in many difference circumstances, both for clear "winners" and "losers" but also for firms that seem to be in ambiguous positions – firms that enter with technology that does not become the dominant design but possess valuable pre-entry capabilities; firms that lack pre-entry capabilities but enter with the technology that becomes the dominant design. In addition, the exploration of different types of exit modes show that although some firms exit the industry, their capabilities live on, shaping the continuing evolution of the industry while other firms exit via dissolution of their capabilities. Furthermore our post-hoc analysis reveals that despite the enduring effects of capabilities and technology choice, firms are remarkably agile in making changes to firm strategy to compensate for initial strategy choices. In particular, we observe a significant movement of firms downstream into a portion of the value chain requiring different sets of capabilities (systems architecture versus component manufacturing) in an effort to adapt as industry evolves. Hence, while initial strategy factors (pre-entry capabilities and technology choice) have an enduring effect on firm survival, dynamic shifts in strategies post-entry also deserve attention in explaining firms' outcomes. Finally, the observation provides further insights into how when the field of competition is resolved at one level of technology, in this case the dominant design technology in solar PV modules, it may shift to another level of technology, in this case the solar PV system (Murmann and Frenken, 2006).

LITERATURE REVIEW AND HYPOTHESES

Prior research suggests that new industries evolve in similar ways, with a rush of entrants during a period of emergence, followed by an industry shakeout with a high rate of firm exit, and then stabilization into a mature industry (Agarwal and Gort, 2002; Agarwal and Tripsas, 2011; Utterback and Suárez, 1993). Although the stylized pattern of industry evolution has been well established, there are multiple explanations for the eventual fates of firms. Scholars grounded in technology management have viewed industry emergence through the lens of technology choice, arguing that technology competition drives the pattern of emergence, shakeout, and maturity (Abernathy and Clark, 1985; Abernathy and Utterback, 1978; Utterback, 1996). Industries begin with a technology breakthrough and progress through an era of ferment during which many firms enter pursuing differing technology alternatives along competing technology paths (Clark, 1985). The era of ferment ends with the establishment of a dominant design—the synthesis of components along a particular technology path that, although itself may not be at the technology frontier, best meets the performance-cost tradeoffs of a majority of the market (Anderson and Tushman, 1990; Suarez and Utterback, 1995). Although there are differing theories as to the cause of the dominant design (see Murmann and Frenken, 2006 for a summary), prior work agrees that the dominant design leads to a fundamental change in the nature of competition that increases the pressures on firms and often results in increased rates of exit (Utterback, 1996; Utterback and Suárez, 1993).

At the level of the firm, research highlights that a firm's choice to pursue a specific technology represents a boundedly rational decision *ex ante* – one that is based on the nature of the technology and the nature of the firm's assets and capabilities (Kapoor and Furr, 2015; Wu, Wan, and Levinthal, 2013). But that at later period, when the dominant design emerges and the uncertainty gets resolved, firms that chose the technology that eventually gets established as a dominant design have survival advantage over those that did not (Anderson and Tushman, 1990; Utterback and Suárez, 1993). Furthermore, firms enter earlier and thus have more time to learn before the establishment of the dominant design (Suarez and Utterback, 1995) or firms that enter during the "window of opportunity" just before the establishment of the dominant design (Christensen *et al.*, 1998) are more likely to survive if their technology choice emerges as the dominant design. Therefore, as a baseline, this literature suggests that, holding entry timing and comparative adjustment costs constant, firms that enter with the technology that becomes the dominant design have a lower likelihood of exit.

Separate from the technology management literature, evolutionary economics scholars describe a similar pattern of industry emergence, with new industries being characterized by a large number of initial entrants preceding sales takeoff, followed by an industry shakeout and the stabilization into a mature industry (Agarwal, 1997; Agarwal and Bayus, 2002; Agarwal and Gort, 1996). Although the evolutionary economics perspective acknowledges the role of innovation on industry life cycles (Gort and Klepper, 1982; Schumpeter, 1934), this literature tends to focus predominantly on explaining firm outcomes through the lens of pre-entry capabilities (Helfat and Lieberman, 2002). Specifically, scholars have emphasized the differences between diversifiers that bring pre-entry organizational capabilities to an industry and start-ups that bring founder experience and skills but not pre-entry organizational capabilities (Dosi, Nelson, and Winter, 2000; Kapoor and Furr, 2015).

Diversifiers typically enter a new industry with organizational, technological, and/or marketing capabilities that are an important source of advantage (Carroll *et al.*, 1996; Ganco and Agarwal, 2009; Klepper and Simons, 2000). Such advantages may derive from the ability to spread development and commercialization capabilities across multiple markets to achieve economies of scope (Klepper, 2002b; Klepper and Simons, 2005), from leveraging more well-developed capabilities to accelerate commercialization, from utilizing existing complementary capabilities and assets to distribute or market an innovation, or from other sources of advantage due to pre-entry capabilities, including a capability to enter new markets (Helfat and Lieberman, 2002; Kapoor and Furr, 2015; Wu *et al.*, 2013). The disadvantage of pre-entry organizational capabilities is that they can create inertia around existing capability trajectories, thereby biasing strategy choices to preserve existing capabilities (Ganco and Agarwal, 2009; Kapoor and Furr, 2015; Wu *et al.*, 2013).

By contrast, start-ups lack such pre-entry organizational capabilities, and this can be an advantage since they are free from the inertia created by pre-entry organizational capabilities. Moreover, start-ups bring valuable experience from founders, both from within and outside the industry, and that may help them compete in the industry (Agarwal *et al.*, 2004; Ganco and Agarwal, 2009; Klepper and Thompson, 2006; Qian, Agarwal, and Hoetker, 2012). That being said, the pre-entry experience possessed by start-up founders can still bias strategy choices (Furr, Cavarretta, and Garg, 2012). Furthermore, start-up entrants may suffer from a lack of resources, time compression diseconomies in the development of new capabilities, and other limitations associated with the liabilities of newness that decrease their ability to develop sufficient stocks of capabilities, relative to diversifiers, before the onset of an industry shakeout (Bruderl and Schussler, 1990; Dierickx and Cool, 1989; Stinchcombe, 1965). Such limitations can be particularly acute for firms in technology-based industries which require both the development of technologies as well as organizational capabilities, sometimes during comparatively short windows before industry pressures lead to a shakeout. Thus, despite the advantages to flexibility associated with start-up entrants, research on the effect of pre-entry organizational capabilities on firm survival during industry shakeout suggests that having pre-entry organizational capabilities, particularly during the emergence and shakeout phases, confers survival advantages (Carroll *et al.*, 1996; Khessina and Carroll, 2008; Klepper and Simons, 2000; Mitchell, 1994), even when accounting for environmental and experience contingencies (Ganco and Agarwal, 2009; Sarkar *et al.*, 2006). Therefore as a baseline, this literature suggests that firms that entered with pre-entry organizational capabilities will have a lower likelihood of exit than those firms that lack these capabilities.

Although both the technology management and evolutionary economics literatures provide valuable insights regarding the role of technology entry choice and pre-entry capabilities on firm exit during industry shakeout, because these factors have been examined independently from one another, we have only a partial view of industry evolution, one that emphasizes "winners" and "losers" along a singular dimension such as technology entry choice or pre-entry capabilities. However, as industries emerge firms make choices under conditions of uncertainty, some of which are revealed to be fortuitous and others less so. Firms may, for example, enter with the technology that does not become the dominant design but may still possess the advantages stemming from pre-entry organizational capabilities, or alternatively firms may lack pre-entry organizational capabilities but may have been fortunate enough to have entered with the technology that eventually becomes the dominant design. The existing theories that are premised on only firms' technology entry choice or only pre-entry capabilities will not be able to resolve these cases.

We offer a theoretical framework that accounts for firm-level heterogeneity both in terms of pre-entry capabilities and technology entry choices. Figure 1 illustrates the organization of our framework. Each quadrant represents a case for whether the firm is a diversifying or a start-up entrant, and whether the firm's technology choice at entry is the technology that becomes the dominant design or not.[1]

<<< Insert Figure 1 about here>>>

Firms in quadrant 4 are those with pre-entry capabilities who enter with the technology that becomes the dominant design. Even though both start-ups and diversifiers may have chosen the technology that eventually becomes the dominant design, a diversifier's stock of pre-entry capabilities, resources, and complementary assets may provide the firm a lead in developing the capabilities to commercialize a technology, because they can leverage or further refine existing capabilities rather than develop them from scratch, providing them advantages in the speed and quality of commercialization (Kapoor and Furr, 2015; Wu *et al.*, 2013). Furthermore, because survival in the post-dominant design era is often associated with the ability to achieve economies of scale in development and production (Argyres, Bigelow, and Nickerson, 2013; Klepper, 2002b; Utterback, 1996), diversifiers may use such capabilities to quickly fortify their possession

[1] An important assumption within the technology management literature on industry emergence is that firms' technology choices are typically sticky and while the possibility of switching technologies as industry evolves exists, such cases are assumed to be rare (Suarez and Utterback, 1995). This is because firms develop technology-specific resources and capabilities on competing design paths, which require significant adjustment costs to change (Clark, 1985;Argyres et al., 2012). Such costs typically increase over time as firms become embedded in a particular technology trajectory (Abernathy and Utterback, 1978).

of the winning technology once a dominant design has been established, giving them an even greater advantage over firms that lack pre-entry capabilities or entered with a different technology. Thus we suggest that the benefits of entering with the technology that eventually becomes the dominant design are enhanced when firms possess pre-entry capabilities. Hence, the likelihood of exit will be lowest for firms in quadrant 4.

By contrast, firms in quadrant 1 are those without pre-entry capabilities and who enter with a technology that does not become the dominant design. Such firms made a boundedly rational choice at entry during a period of uncertainty (Kapoor and Furr, 2015), but as the technology competition resolves and a shakeout begins, they find themselves with experience and resources in the non-dominant technology that are no longer as valuable. In addition to finding their technology-specific capabilities are no longer as valuable, because these firms entered without pre-entry organizational capabilities, given resource and capability development constraints, their stock of industry-specific capabilities will also be lower than firms that entered with pre-entry organizational capabilities. Hence the likelihood of exit will be greatest for these firms during an industry shakeout.

What then might one expect for firms with pre-entry capabilities that entered with a technology that does not become the dominant design (Quadrant 3) or for firms without pre-entry capabilities but entered with the technology that becomes the dominant design (Quadrant 2)? If firms with pre-entry capabilities enter with a technology that does not become the dominant design (Quadrant 3), the latent prediction would be that these firms will likely exit. Although this may be true in general, the establishment of a dominant design does not necessarily mean complete market dominance of that technology (Anderson and Tushman, 1990) and thus firms may be able to reposition around market niches (Abernathy and Clark, 1985; Adner and Snow, 2010) or change their business model to adapt to the new competitive conditions (Teece, 2010). Although such changes are possible, it may be possible that diversifiers are inertial and thus too slow to make such changes (Kapoor and Klueter, 2014; Mitchell, 1989). At the same time, research demonstrates that despite the stereotype of being agile, start-ups can also be inertial in making changes, particularly when it relates to technology investments (Furr *et al.*, 2012). Therefore inertia alone cannot explain the ability to adapt to a technology choice that is later revealed to be sub-optimal.

By contrast, the capability lens provides insight into how firms may adapt to these conditions. Specifically, diversifiers that enter an industry possess different types of pre-entry capabilities, one of the most relevant to this situation being integrative capabilities. Integrative capabilities are corporate level capabilities which can be deployed within or across industries or value chains (Helfat and Campo-Rembado, 2014; Helfat and Raubitschek, 2000; Qian *et al.*, 2012). These capabilities are characterized by corporate level knowledge of how to integrate, coordinate, and adapt activities across value chains (Helfat and Eisenhardt, 2005; Moeen and Agarwal, 2015). In a situation where a firm with such capabilities discovers that it entered with the technology that did not become the dominant design, the firm may still be able to leverage these integrative capabilities to compete in the industry. For example, the firm may be able to leverage economies of scope to compete against the dominant design technology, employing its marketing and distribution capabilities to reposition around an industry niche, or using its capabilities to employ a new business model that allows it to survive in the industry.

What is important from a strategy perspective is that these firms, having discovered that they entered with a technology that fails to become the dominant design, do not by definition fail, as might be inferred from a dualistic technology choice perspective. Although a dominant design may emerge, there are supply and demand side factors that may create the circumstances that allow firms with integrative capabilities to survive. From a supply-side perspective, although the industry may experience a shakeout as design and cost pressures lead to the elimination of less efficient producers, as costs of production come down, the overall market may continue to grow, providing an incentive to remain involved in the market. It may be that a firm with integrative capabilities can find a way to maintain its competitiveness on the supply side. For example, after the establishment of a dominant design, typically reductions in production cost occur as firms shift their attention to process innovations instead of product innovations. It is the reduction in production costs that reinforce the dominant design and contribute to industry shakeout. But a firm with integrative capabilities may be able to borrow process innovations from other parts of its business or other industries to remain competitive. To illustrate, although the cumulative body of process innovations in cSi may give cSi producers an advantage over non-cSi producers, a non-cSi producer with significant capabilities in thin film manufacturing in other industries and the integrative capabilities to recombine them with their non-cSi PV production could find ways to remain competitive with an alternative technology.

From a demand side perspective, although a dominant design may emerge, most industries are characterized by market niches in which alternate technologies continue to thrive because they match the unique needs of these segments. Firms with integrative capabilities may be better able to reconfigure their marketing and distribution to satisfy a particular market niche than firms without such capabilities. Perhaps even more importantly, a firm may leverage its integrative capabilities to alter the business model in a way that provides it an advantage that compensates for the higher cost of production through a cross-subsidization that makes continued activity in the industry attractive. For example, the firm may be able to leverage its integrative capabilities to establish downstream relationships or even integrate downstream and then use the profits from this business to cross-subsidize the manufacturing business.

Therefore, we predict that the liabilities of entering with a technology that fails to become the dominant design may be partially offset by possessing integrative pre-entry capabilities. Although we do not expect such firms to fare as well as those with pre-entry capabilities and that enter with a technology that becomes the dominant design (quadrant 4), they nonetheless have a greater likelihood of survival than firms lacking both (quadrant 1) precisely because they can leverage their pre-entry capabilities to make post-entry strategy changes.

What then may be the case for firms that lack these valuable pre-entry capabilities but which were fortunate enough to enter with the technology that becomes the dominant design (quadrant 2)? Although these firms lack these valuable capabilities, because they entered in the technology that becomes the dominant design, they will have developed post-entry, technology-specific capabilities (Helfat and Lieberman, 2002; Teece, 1986) that, after the emergence of the dominant design, have increased value in the industry. Although these firms may have lesser stocks of these capabilities than firms with both pre-entry capabilities and who also enter with the technology that becomes the dominant design (quadrant 4), they will nonetheless are better positioned than those firms that lack pre-entry capabilities and that entered with a technology that did not become the dominant design (quadrant 1).

Hence, in the context of industry emergence we expect that in some cases the liability of entering with the technology that does not become the dominant design will be offset by firms' pre-entry organizational capabilities. In other cases, the disadvantage stemming from the lack of pre-entry organizational capabilities maybe offset by entering with the technology that becomes the dominant design. Thus the factors identified in prior literature as predictors of survival versus exit, may also act as buffers for entrants into an industry, cushioning them against exit.

H1: The likelihood of firm exit will depend on the joint incidence of technology entry choice and pre-entry organizational capabilities: lowest for firms with pre-entry capabilities who enter with the technology that becomes the dominant design, highest for firms lacking pre-entry capabilities and who enter with a technology that does not become the dominant design, and intermediate when one factor is present and the other is not (i.e., Q1> Q2, Q3 > Q4).

Exit Pathways: Acquisition versus Dissolution

The pattern of industry evolution suggests that when industries undergo a shakeout, the number of firms participating in the industry are drastically reduced as many firms exit the industry. Prior theoretical and empirical work in evolutionary economics, technology management, and population ecology has treated such exits as dissolutions, meaning that as the opposite of firm survival, exits represent the dissolution of the firm and its capabilities. Nevertheless, related literatures which study firm exit in other contexts suggest potentially important distinctions for the study of industry evolution. For example, the finance and accounting literatures, which examine exit through the lens of shareholder returns, make clear distinctions between three types of exit with differing implications for shareholders: survival, dissolution (e.g., bankruptcy or liquidation) and acquisition (usually distressed), with acquisition being preferred over bankruptcy due to the increased returns to shareholders (Astebro and Winter, 2012; Balcaen *et al.*, 2012; Pastena and Ruland, 1986; Peel and Wilson, 1989). Similarly, the entrepreneurship literature, which studies exit through the lens of returns to the entrepreneur and shareholders, also makes a distinction between survival, dissolution, and acquisition and emphasizes the desirability of acquisitions either as "harvest" events when firms are acquired at a premium or as opportunities to exit, even if at a loss, and pursue more attractive opportunities (Arora and Nandkumar, 2011; DeTienne, McKelvie, and Chandler, 2015).

Likewise, if acquisitions are viewed through the lens of capabilities and resources, they are significantly different events from dissolution because acquisitions result in the redeployment of capabilities and resources to another firm rather than in their dissolution (Fortune and Mitchell, 2012). The redeployment of capabilities via acquisition during industry shakeout is important from the perspective of the acquirer, the acquired, and the industry. In the case of the acquired, acquisition signals that the firm developed valuable capabilities and assets that retain their value in the industry. Although the firm may exit for any number of reasons related or unrelated to the value of its capabilities (e.g., internal or external capital constraints, inappropriate option pricing which results in pre-mature termination, position in unfavorable ecosystems, etc.), it nonetheless succeeded in developing valuable capabilities and thus is not equivalent, in terms of exit, to dissolution which results in the termination of both the firm and its capabilities. From the perspective of the acquirer, a distressed acquisition may be an opportunity to obtain valuable capabilities and assets at a discount relative to acquisitions in more stable or growth periods and thereby consolidate an advantageous market position. From the perspective of the industry, such acquisitions mean valuable capabilities and assets continue to contribute to the development of the industry, even though the initial developers no longer own those capabilities.

Such patterns of capability redeployment through acquisition are reflected in the solar PV industry. During the industry shakeout, solar PV firms failed for many reasons, not all of them because of a failure to develop valuable capabilities. In particular, from the perspective of the acquired firms, many of these firms exited because they experienced internal capital constraints and external capital providers, such as venture capitalists were unable to provide the expected, continued support of their ventures (Westerlind, V. 2008. Personal Interview). Similarly, from the perspective of the acquirers, many of the acquirers were able to purchase valuable capabilities from previous competitors at discounts uncharacteristic of a typical market for corporate control. Finally, at the level of the industry, without distressed acquisition, many valuable capabilities, particularly among non-crystalline silicon technologies that did not become the dominant design, would have been eliminated but instead were purchased and continued to be deployed in specific market niches.

This redeployment of firm capabilities, particularly for the case of distressed acquisitions during shakeout, are a critical aspect of industry evolution. Such capabilities may be those related to technology that gets established as a dominant design. Given that economies of scale in research and development as well as in production have been demonstrated to be critical to survival as the industry evolves (Argyres *et al.*, 2013; Klepper, 2002b; Utterback, 1996), acquiring firms may be eager to purchase competitors in the winning technology that decide to exit and thereby increase their own scale. Alternatively some entrants may find that they are faced with internal capital constraints or that the returns fall below their expectations (Arora and Nandkumar, 2011; Noda and Bower, 1996), and even though they may have developed valuable resources and capabilities in the winning technology that could be used within the industry, choose to exit regardless, making such capabilities attractive targets for acquisition. Hence, although firms may exit for many reasons, firms that enter with the technology that gets established as a dominant design are more likely to possess valuable capabilities that increase their likelihood of acquisition and decrease their likelihood of dissolution.

Hypothesis 2: Among firms that exit during industry shakeout, firms that entered with the technology that becomes the dominant design are less likely to exit via dissolution (as opposed to acquisition) than firms that entered with other technologies.

It may also be the case that diversifiers who possess pre-entry capabilities, regardless of the technology choice, may be less likely to dissolve upon exit and more likely to be acquired.[2] Such may be the case because capabilities require time and investment to develop and thus firms entering with pre-entry capabilities have a greater chance of developing larger and more valuable stocks of these capabilities given their head start in developing such capabilities. These stocks of capabilities may be attractive to acquirers because they can be redeployed in the industry. For example, in their study of exits after the dot com bubble, Fortune and Mitchell (2012) found that firms possessing managerial capabilities were more likely to be acquired than dissolved, presumably because those managerial capabilities could be re-deployed. In industries that require the commercialization of technology, organizational capabilities, such as those related to production, distribution, or management, may be particularly valuable because they can be quickly redeployed to accelerate or increase the scale of technology commercialization. Furthermore, these firms may also have integrative capabilities, developed in previous experience of entering or operating in industries that facilitate the development of more complete or valuable capability sets, either around the dominant design technology, or in the case of non-dominant technologies, around market niches or alternative business models (Helfat and Campo-

[2] We use the term dissolve as an umbrella term for the modes of exit identified in the prior literature that lead to the dissolution of firm capabilities, which include, failure of the firm, withdrawal from the focal industry, and liquidation/bankruptcy without continued activity in the industry.

Rembado, 2014; Helfat and Lieberman, 2002). In other words, because these firms have experience developing and coordinating value chains, the capability bundle they develop could be particularly attractive to acquirers looking to consolidate in an industry because they require less investment and modification than a capability bundle developed by a firm lacking such resources (either because there are more likely to be capability gaps or because that firm's capability bundle is more likely to be idiosyncratic, making it more difficult to integrate into the firm's existing activities). Thus, we predict:

Hypothesis 3: Among firms that exit, diversifying entrants with pre-entry organizational capabilities are less likely to exit via dissolution (as opposed to acquisition) than start-up entrants which lack pre-entry organizational capabilities.

Applying the same logic as that developed for Hypothesis 3, it may be that possessing the technology which becomes the dominant design and pre-entry organizational capabilities act jointly to decrease the likelihood of dissolution relative to acquisition and the lack of these factors act jointly to increase the likelihood of dissolution relative to acquisition. It may also be the case that one factor, rather than acting as a buffer to exit, acts as a factor making a firm moderately attractive for acquisition rather than dissolution. For example, although a start-up may lack pre-entry organizational capabilities, if that start-up made investments in the technology that becomes the dominant design, it may be an attractive target for acquisition to firms looking to consolidate their industry position. Alternatively, even though a diversifier may have entered with a technology that is later revealed to be a non-dominant design, the diversifier may have repositioned around a market niche or developed a valuable business model that makes it an attractive acquisition. Thus we predict that:

Hypothesis 4: Among firms that exit, the likelihood of exit via dissolution (as opposed to acquisition) will depend on the joint incidence of technology choice and pre-entry organizational capabilities: lowest for dominant design technology choice and pre-entry organizational capabilities, highest for non-dominant design technology choice and lack of pre-entry *capabilities, and intermediate for when one factor is present and the other is not (i.e., Q1> Q2, Q3 > Q4).*

RESEARCH CONTEXT

We explore our arguments in the context of the global solar PV industry from 1978 to 2015. The solar photovoltaic industry has become one of the pillars of the renewable energy sector, supplying an increasing proportion of the world's energy, expanding consistently throughout the period of study, and generating annual revenues in the billions of dollars. In addition to the environmental and economic importance, the global PV industry represents an excellent setting in which to examine the emergence and shakeout of a major industry characterized by technology competition. In this analysis we focus on manufacturers of solar PV modules, which are used to convert sunlight into electricity. A large number of both diversifying and start-up entrants pursued different technology choices, namely crystalline silicon wafer and different variants of non-crystalline silicon technologies, competing to become the dominant technology. The period between 1978 and 2015 presents an appropriate window to test our predictions. This time period captures the emergence of the global PV industry as a major industry, with significant entry during the 1980s and 1990s that peaks and falls of sharply in 2008, followed by establishment of the dominant design and industry shakeout wherein almost 40% of the industry participants leave the industry with exits peaking in 2014 and then falling off sharply as the industry evolves towards maturity. Hence our analysis captures the entire wave of entry into the emerging industry and the primary shakeout due to establishment of a dominant design.

Data

The data comes from both primary and secondary sources. The study is part of a larger industry research project in which we conducted extensive fieldwork spanning 40 months between 2006 and 2015 to understand the emergence, evolution, and shakeout of the industry.

Over the course of our research we have interviewed over 40 industry professionals, including PV solar scientists, PV cell and module manufacturers, PV installers, industry analysts, and investors, employing a semi-structured interview format that lasted on average of 1.5 hours. In addition we made several half-day to full-day site visits to solar PV manufacturing plants, research labs, and industry conferences in an effort to understand the evolution of the industry. Finally we studied the historical evolution of the industry through the review of the two most comprehensive industry journals, *PV News* and *Photon International*.

The data for the quantitative analysis come from a proprietary industry database maintained by Greentech Media (www.greentechmedia.com). Greentech Media is widely regarded as the leading industry analysis organization for the solar PV industry. The database contains information on 239 public and private firms that account for the majority of the solar PV industry output since its origins (the database accounts for over 95% of total industry production). We gathered self-reported data on firm's entry year, exit year, and exit mode as well as pre-entry and post-entry characteristics from company websites and public filings, which we then verified through phone calls to the company when possible. All reports of exit year and exit mode were corroborated by external sources. Data on industry sales were obtained from *Progress in Photovoltaics* (the leading peer reviewed journal dedicated to the PV industry), *Photon International*, and Greentech Media.

Industry Background

Firms in the solar PV module industry manufacture devices that employ a semiconductor material to convert sunlight directly into electricity. Solar PV modules are typically flat panels composed of 32-76 solar cells, wired together in a series, and enclosed in weatherproof sandwich of glass and insulating materials. The photovoltaic effect, or the conversion of light into energy, was first discovered by Alexandre-Edmond Becquerel in 1839. However the first PV modules designed for terrestrial use were not developed until 1955 by Bell Labs. Several initial attempts to develop commercial PV modules failed because cost per watt to produce the technology was orders of magnitude more expensive than electricity produced by mainstream power plants. However, continued improvement in PV technologies and the renewal of supportive policies due to global energy and environmental concerns led to the emergence of the solar PV industry. The pattern of firm entry, firm exit and industry shakeout in the solar PV industry mirrors the stylized pattern described in the literature on industry evolution. After an initial period of slow entry during the 70s and 80s, entry began to increase during 1990 and peaked in the 2000 era. This growth period was characterized by a pattern of increasing entry and sales, that has been observed in other industries (Agarwal and Tripsas, 2011; Bayus, Kang, and Agarwal, 2007). During this period firms entered and commercialized modules drawing on four different technologies (crystalline silicon, cadmium telluride, CIGS (copper-indium-gallium-diselenide), and amorphous silicon): these technologies employed different semiconductor materials that required specialized manufacturing processes and had different product properties (e.g., variance in light absorption, efficiency, etc.) although all modules ultimately produced electricity (for an expanded description of the different technologies see Appendix A). Although crystalline silicon (cSi) technology was the first to be commercialized, all the commercialized technologies competed for some time without consensus about which technology would be the dominant design (Ardani and Margolis, 2011; Bradford, 2006; Chopra, Paulson, and Dutta, 2004; Peters *et al.*, 2011).

Accordingly both established and start-up firms entered in large numbers to pursue each of the technologies in hopes of establishing their technology choice as the dominant design. After decades of decreasing market share, the market share for cSi began to increase dramatically starting in 2008. There are multiple potential contributing factors. Since the early part of the decade, the supply of silicon material had become a major constraint in the industry, with silicon prices increasing seven-fold. In response to this supply-demand imbalance, PV manufacturers and suppliers of manufacturing equipment strained to improve cSi technology and decrease costs in order to survive relative to the other competing technologies, leading to major improvements in manufacturing processes and the ecosystem of available technologies around cSi (Kapoor and Furr, 2015). At the same time, silicon producers expanded production, which became available in significant quantity in 2008, leading to a return to historically modest silicon prices. The improvements in cSi module manufacturing and the fall in cost of silicon inputs revealed a significant price/performance advantage for cSi in 2008, characteristic of a dominant design. Furthermore, many industry analysts, looking in retrospect, began to conclude that cSi had become the dominant design relative to non cSi technologies around this time period(Mehta, 2010). As a result, beginning in 2008, an industry shakeout began to occur, leading to the exit of firms in all technologies, which peaked in 2013 and continued through 2014 until the industry began to re-stabilize in 2015 (see Figure 2). In Figure 2 it appears that slightly more firms entered with cSi technologies than with non-cSi technologies, more non-cSi firms exit during the industry shakeout (although many cSi firms also exit). Finally in Figure 3, many more diversifiers appear to have entered than start-ups, and although slightly more absolute numbers of diversifiers appear to exit during the shakeout than start-ups, as a proportion of total entrants in that category, a greater proportion of start-ups that entered exited the industry during the shakeout.

<<<Insert Figures 2-4 about here>>>

EMPIRICAL ANALYSIS

Dependent Variable

Hypotheses 1 predicts likelihood of firm exit during the industry shakeout. The dependent variable, exit, is a binary variable equal to 1 if the firm exits PV module manufacturing and zero otherwise. For hypothesis 1, the characterization of exit event is consistent with prior literature in industry evolution, population ecology, and technology management as termination of the firm as an independent entity for any reason (Agarwal, 1997; Bayus *et al.*, 2007; Carroll *et al.*, 1996; Suarez and Utterback, 1995), with one notable exception.

Because the focus of our study is exit during industry shakeout, to facilitate comparison of the results for Hypothesis 1 with Hypotheses 2-4, we treat pre-shakeout acquisitions that occurred at a significant price premium for shareholders (and thus are "harvest" events distinct in character from the hypothesized events) as censored observations. Such pre-shakeout acquisitions represent less than 5% of the exits and the results we report are robust to their inclusion.

Hypotheses 2-4 predict the hazard of exiting via dissolution versus acquisition. The dependent variable, dissolution, is a binary variable equal to 1 if the firm exits PV module manufacturing via dissolution and zero otherwise. Consistent with prior literature, dissolution includes bankruptcy, wherein the firm's assets are disaggregated and auctioned; withdrawal, wherein a diversified entrant exits the focal industry but remains active in other industries; and dissolution, wherein the firm ceases operations with or without piecemeal liquidation of assets whereas acquisition includes cash or equity mergers and acquisitions (Astebro and Winter, 2012; Cefis and Marsili, 2012; DeTienne *et al.*, 2015).

Independent Variables

Testing hypotheses required that we categorize firms based on whether they entered the industry with the technology that became the dominant design or an alternative technology. The variable cSi takes a value of 1 if the firm entered with the crystalline silicon (cSi) technology which eventually became the dominant design and 0 f the firm entered with other competing technologies. Because commercializing a solar PV module requires significant technology-specific investments (both financial and human capital), 93% of firms commercialized only one technology. Nonetheless 17 firms made investments in a second technology, 14 of which were founded to commercialize cSi technology and afterwards commercialized a non-cSi technology, suggesting that the technology competition was sufficiently real that even for firms possessing the technology that eventually became the dominant design, some were willing to undertake the investments to commercialize a second technology as an option on the future. For the fraction of firms pursuing a second technology, we categorized firms based on the technology the firm commercialized at founding because it represents the initial strategic intent of the firm and because the firm has had the longest period of time to develop capabilities in that technology. We conducted several robustness checks of these categorizations, including omitting firms with a second technology from the analysis, re-categorizing firms that had cSi technology in their portfolio as cSi firms, and including a control for firms possessing a second technology. All the analyses reported were robust to these alternate characterizations. Consistent with prior literature, we categorized a firm as a diversifying entrant if it was an established firm operating in another industry before entering the solar PV industry (Agarwal *et al.*, 2004; Helfat and Lieberman, 2002) and as a start-up otherwise.

Control Variables

We include a number of firm and industry level variables to control for both time-varying and time-invariant effects. We include a control for time since entry (*entry*) to account for factors related to firm experience in the industry as well as a quadratic term to account for any curvilinear effects. We control for firm size, measured as the log of total production measured in megawatts. We also control for firms founded in China, since there is some discussion of these firms being advantaged due to access to lower cost financial and human capital. Results are robust to alternate firm-level controls, including measuring firm size in terms of plant capacity rather than actual production and measuring regions at a more granular level (e.g., Europe, North America, Asia). We also include industry-level controls, including well-established measures of competition, calculated as the number of firms in the industry during a given year and the quadratic term to account for any curvilinear effects. To control for industry size, we include a measure of gigawatts of global industry production. Finally, to account for timing of entry relative to the dominant design (Suarez and Utterback, 1995), we include two variables (*years before DD* and y*ears after DD).* The first variable equals the year of the establishment of the dominant design (i.e., 2008) minus the year of entry for firms that entered before the dominant design (and zero otherwise) and the second equals the year of entry minus the year of the dominant design for firms that entered after the dominant design (and zero otherwise). We explored alternative controls to account for industry level trends, including industry growth rate, three-year moving average industry growth rate, technology clocks to account for relative maturity of the different technologies that firms entered with, density by technology rather than industry, and industry size by technology. Results are robust to these alternative controls. Results are also robust to using lagged values of control variables.

Model

To model firm exit (Hypotheses 1), prior empirical work has employed both continuous and discrete-time hazard models. Early work on industry evolution typically employed the Cox proportional hazards model because it had the advantage of making no assumptions about the baseline hazard, or a parameterized model employing a Gompertz or Weibull distribution (Allison, 2014; Cleves *et al.*, 2010). The disadvantage of the Cox model is that failure times recorded in annual intervals may create many ties which require additional assumptions that decrease estimate efficiency. More recent empirical work on industry evolution frequently employs discrete-time hazard models, particularly complementary log-log distributions, because they have the added advantage of accommodating exit measured in yearly intervals but is directly comparable to the Cox proportional hazards model (Allison, 2014; Sarkar *et al.*, 2006). We test our predictions using the complementary log-log discrete-time hazard model with random effects, to account for unobserved heterogenity between firms (also referred to as frailty, or unobserved factors that may predispose the subject to an event (in this case failure)), thereby providing a more conservative test of our hypotheses. Hypotheses 2-4 predict the hazard of dissolution relative to acquisition. To test these, we restricted the sample to firms that exit and estimate the likelihood of dissolution, relative to acquisition, using a logit model.

RESULTS

Table 1 provides descriptive statistics and correlations for the variables in the analysis. Table 2 reports the results from the discrete-time event history, complementary log-log models to test Hypotheses 1. Nine firms were dropped because they for lack of data on size, leaving a sample of 230 firms. Model 1 is the baseline model with control variables. Model 2 introduces firm's technology entry choice (*cSi*) to test Hypothesis 1. Model 3 adds the effect of pre-entry organizational capabilities (*diversifier*), and Model 4 adds categorical variables that correspond to the quadrants with the omitted category of start-ups entering with non-cSi technology.[3] It is worth noting that although we hypothesize about the joint effect of technology choice and pre-entry capabilities, our theory suggests an empirical test for firms in qualitatively different categories rather than testing for simple interaction effects, which interaction effects can be particularly difficult to interpret in non-linear models wherein each interaction can have a different slope and intercept (Norton, Wang, and Ai, 2004). Therefore, as suggested by prior work, a test employing categories is more appropriate than a test that adds an interaction term (Adner and Kapoor, 2015; Norton *et al.*, 2004). Table 3 reports the results for the logit model predicting dissolution (1) versus acquisition (0) for testing Hypotheses 2-4. Model 5 is the baseline model with controls. Model 6 tests the effect of the technology choice variable. Model 7 adds the effect of pre-entry organization level capabilities, and Model 8 adds categorical variables to explore the joint effect of these two variables.

All coefficients are reported as log odds, which means that a negative coefficient is associated with a decrease in log odds (which can be interpreted as the decrease in the odds ratio) whereas positive coefficients are associated with an increase in log odds (or an increase in the odds ratio). The results from the baseline Model 1 are highly consistent with prior research. *Density* has an inverted-U shape impact on the survival of firms, first increasing survival rates and then decreasing as the population becomes crowded (Carroll *et al.*, 1996; Hannan and

[3] Note that our theory suggests an empirical test to observe the effects for firms in qualitatively different categories rather than testing for simple interaction effects, which interaction effects can be particularly difficult to interpret in non-linear models because each interaction

Carroll, 1992). Similarly, the estimates for *years before DD* and *years after DD* confirm that entrants who enter early before the onset of the dominant design have survival advantages whereas those who enter late after the dominant design has been established have higher mortality rates (Suarez and Utterback, 1995; Utterback and Suárez, 1993). Furthermore, the effect of *age* (older firms may be more inertial or locked into early technologies far from the technological frontier) and *entry* (competitive entrants in any given year), which are significant and positive, and the coefficient for firm *size* (greater resources to buffer against failure), which is significant and negative are consistent with the findings from prior research (Agarwal and Bayus, 2002; Agarwal *et al.*, 2004; Agarwal and Tripsas, 2011).

More notably, in Table 2, the coefficient for technology choice, *cSi*, is negative and significant ($p<0.01$), confirming prior empirical work that entering in the technology that becomes the dominant design decreases the likelihood of failure. Interpreted in terms of odds ratio (the exponentiated coefficient), estimates from Model 3 suggest that firms that chose the technology that became the dominant design has a 0.41 lower odds of failure, or said differently, a 2.4 times greater odds of survival. Similarly, the coefficient for *diversifier* is negative and significant ($p<0.01$), confirming prior empirical work that possessing pre-entry capabilities decreases the likelihood of failure. As estimated in Model 3, in terms of odds ratio, firms that had pre-entry organizational capabilities had a .48 lower likelihood of failure, or said differently, a 2.1 times greater odds of survival.

Hypothesis 1 argued that diversifying entrants who enter with the technology that became the dominant design will have the lowest likelihood of exit, start-up entrants who enter with other technologies will have the highest likelihood of exit, and start-ups with dominant design technology as well as diversifiers with other technologies will have an intermediate likelihood of exit. The magnitude and sign of coefficients for firm type and technology choice in Model 4 support our prediction. Start-ups that enter with technologies that did not become the dominant design (omitted category) have the highest likelihood of exit. The magnitudes of the coefficients for firms in the other categories are in the expected order with diversifying entrants that enter with cSi, the dominant design, having the lowest likelihood of exit (0.20 lower odds of failure, or 5 times higher odds of survival), followed by start-ups that enter with cSi (0.45 lower odds of failure, or 2.2 times higher odds of survival), and diversifiers that enter with other technologies (0.51 lower odds of failure, or 1.9 times higher odds of survival) compared to start-ups that enter with technologies that do not become the dominant design. Additional statistical tests comparing coefficients suggest that the coefficient for *cSi & diversifier* is statistically different from the other categories, and as predicted, the coefficient for *non-cSi & diversifier* and *cSi & start-up* are not different at a statistically significant level ($p<0.73$).

Hypotheses 2-4 predict the likelihood of dissolution over acquisition for exiting firms. Hypothesis 2 predicts that exiting firms which entered with the technology that was established as a dominant design are less likely to exit via dissolution. The coefficient for technology choice (*cSi*) in Model 6 is negative and significant ($p<0.01$) supporting the hypothesis. Estimates from model 7 suggest that firms that enter with the technology that became the dominant design (*cSi*) had 0.20 lower odds of dissolution relative to acquisition, or 4.6 times greater odds of acquisition. Hypothesis 3 predicts that firms with pre-entry capabilities are less likely to exit via dissolution relative to acquisition. The coefficient for *diversifier* in Model 7 is negative but not significant ($p<0.62$), failing to provide support for the hypothesis. Hypothesis 4 predicts that firms with pre-entry capabilities (diversifiers) that entered with the technology that became the dominant design will have the lowest likelihood of exit via dissolution relative to acquisition, firms that lack both of these will have the highest likelihood of exit via dissolution relative to acquisition, and firms having one (pre-entry capabilities) or the other (entering with technology that became the dominant design) will have an intermediate likelihood of exit through dissolution relative to acquisition. The estimated coefficient for diversifiers that enter with cSi is negative, has the highest magnitude, and is statistically different from all other categories. Estimates from Model 8 suggest these firms had a 0.17 lower odds of dissolution, or a 5.8 times greater odds of acquisition. The coefficients for *non-cSi & diversifier* and *cSi & start-up* are statistically insignificant. Hence, these results provide only partial support for Hypothesis 4, that the likelihood of dissolution is lowest for diversifiers that enter with cSi, whereas there is no statistically significant difference in dissolution likelihood among other entrants.

These results are robust to a number of additional checks. As robustness check for Hypotheses 1, we retested the model using discrete-time hazard models employing a standard complementary log log distribution (without random effects) and a logistic distribution. In addition we also repeated the tests using continuous time models, using both a Cox proportional hazards model (with both Breslow and Efron approaches to handle ties) and a Cox model with Gompertz distribution (Agarwal *et al.*, 2004; Bayus *et al.*, 2007; Bhaskarabhatla and Klepper, 2014; Chen, Williams, and Agarwal, 2012; Fortune and Mitchell, 2012; Sarkar *et al.*, 2006). For Hypotheses 2-4, as robustness checks, we employed a multinomial logit model that jointly estimates survival, dissolution, and acquisition as well as Cox competing risks models (both a competing risks model which estimates the cumulative hazard of competing risks and a model which holds the excluded exit type as censored). These alternate specifications yielded similar results.

Post-hoc analysis: Related pre-entry capabilities

Because Hypotheses 3 and 4 regarding the impact of pre-entry capabilities on acquisition versus dissolution were only partially supported, we conducted a post-hoc analysis that examines the effect of related versus unrelated pre-entry capabilities on exit pathways. Prior theoretical and empirical work has emphasized the importance of the relatedness of entrants' pre-entry capabilities on technology choice (Kapoor and Furr, 2015) and survival (Klepper and Simons, 2000). Possessing related pre-entry capabilities may also impact how firms exit. To identify a firm's pre-entry capabilities we rely on a firm's self-reported North American Industry Classification System (NAICS) code for diversifiers and on the founder's primary industry experience for start-ups. Following Helfat and Lieberman (2002), we categorize each firm as having pre-entry capabilities (in the case of diversifiers) or founder experience (in the case of start-ups) that is related or not to the commercialization of solar PV modules. Related pre-entry capabilities/experience include semiconductor manufacturing capabilities and solar PV manufacturing, marketing and distribution capabilities, since these may help firms to manufacture or to sell the modules that they produce.

Table 4, Model 9 reports the results of a logit analysis of dissolution relative to acquisition for the sample reported in Table 3, Model 7 but adds the related capability variable. Models 10 and 11 follow the approach in Model 9, but perform separate estimations for the related pre-entry capabilities of diversifiers and the related experience of start-up founders. Finally, although this paper emphasizes the negative survival implications of entering with a technology that loses the competition for dominant design, we did observe a number of firms in this situation but that were acquired. This observation raises an important question: why would firms that enter with the technology that eventually loses then be acquired when they exit? To explore whether this observation is correlated with related capabilities, Model 12 performs an estimation for entrants that entered with technologies that did not become the dominant design.

The coefficient estimate for related capabilities/experience in Model 9 is negative and significant ($p<0.01$), suggesting that related capabilities/experience reduce the likelihood of dissolution relative to acquisition (a 0.21 reduction in odds of dissolution, or 4.7 greater odds of acquisition). However, as Models 10 and 11 illustrate, the significant effect appears to be primarily associated to diversifiers with related pre-entry capabilities and not to startups with related founder experience. In Model 10, where we restrict the sample to diversifiers, the coefficient for *related* is negative and significant ($p<0.02$). By contrast, in Model 11, where we restrict the sample to startups, the coefficient is positive and insignificant ($p<0.12$). Hence, the impact of pre-entry relatedness on the mode of exit is mainly relevant for diversifying entrants and not for start-ups. The result provides insight into Hypothesis 5, which argued that firms who possess pre-entry organizational capabilities are less likely to exit via dissolution than acquisition. Although we did not find support for Hypothesis 5 in the primary analysis, the post hoc analysis suggests that the effect do hold but only for firms with related pre-entry capabilities. For diversifiers with related pre-entry capabilities this translates into a 0.13 reduction in odds of dissolution, or 7.7 times greater odds of acquisition. Lastly, for Model 12 which explores the role of related pre-entry capabilities for firms that entered in the technology that does not become the dominant design, the coefficient is negative and significant ($p<0.05$) suggesting that for firms that entered with non-cSi technologies, pre-entry relatedness made them a stronger candidate for acquisitions (an estimated 0.20 reduction in odds of dissolution, or 4.9 times increase in odds of acquisition). Although limited in scope, the analysis suggests that relatedness does seem to shape mode of exit, particularly for diversifiers and firms entered in non-cSi technologies.

Post-hoc analysis: Post-entry Business Model Change

Prior work in evolutionary economics and technology management focuses almost exclusively on the effects of pre-entry characteristics on the hazard of exit. However, in the hypotheses, we suggested that firms that enter and later find themselves in a suboptimal position may reposition to better weather an industry shakeout. The challenge firms face is that they cannot change their pre-entry capabilities, nor can firms readily change their technology once the dominant design has emerged, since such changes often come with significant penalties including switching costs and time compression diseconomies in developing necessary scale, capabilities, and resources. These challenges are particularly acute in the solar PV industry because manufacturing facilities are capital intensive and technology specific. However, firms can change their business model. Solar PV modules must be combined with other components to create a system that produces electric power. Hence, one change solar PV firms could make is to integrate downstream and provide solar systems rather than modules.[4]

[4] While it is also possible to move upstream into cells, wafers, and polysilicon, this is only a choice for cSi producers since these upstream stages are completed at once in non cSi technologies. Thus with the resolution of uncertainty around the dominant design, moving upstream only provides differentiation within technology choice.

Although such a move sounds natural on the surface, there are significant reasons why firms might avoid moving downstream. Extant theory suggests that as industries evolve, to effectively compete, firms become increasingly specialized (Stigler, 1951). In the environment of an industry shakeout where firms are struggling to survive, firms might remain laser-focused on refining their existing capabilities. Moving downstream could be seen as a distraction since it alters the business model from selling components to other businesses, to selling complete systems to end users, and thus necessitates distinct, new marketing and technical capabilities. Alternatively, as suggested by Helfat (2015), firms may reintegrate in the face of threats if it provides protection against shocks, such as an industry shakeout.

To explore phenomenon, we gathered data about post-entry changes to provide insight into how firms may be making post-entry changes to reposition relative to the industry shakeout. We observed that, as predicted by Stigler (1951), the first entrants into the industry were integrated, followed by an increasing proportion of specialized entrants. However, as the industry shakeout began to emerge, an increasing number of firms began to reintegrate downstream, despite the radical difference between the capabilities required to manufacture solar PV modules and those to design and install solar PV systems.

Table 5 summarizes counts of firms integrated downstream at founding and at last observation.[5] Of the sample of firms (which represent over 95% of production in the solar PV industry), 40 were integrated downstream at entry whereas 131 were integrated downstream at the last observation, an increase of 228%. This increase, which primarily occurred near the time of the industry shakeout, may be the basis for firms' adaptation efforts as discussed in our arguments leading to Hypothesis 1. Consistent with this view, the number of firms in the losing

[5] We categorized firm participation in downstream activities at entry and at last observation (either exit or the last observation at the end of 2015). Although solar systems require several components, the most important downstream activity to the performance of a system is the design and installation of the solar PV system. This is also where most value capture takes place and the primary area where all firms moved when integrating downstream (e.g., if firms moved into inverters they also moved into installation). Therefore, downstream activities are defined as the development of solar systems, namely the design and installation of solar PV systems for residential, commercial, or utility customers.

technology integrating downstream increased three-fold, whereas the number of firms in the dominant design technology integrating downstream increased two-fold. Although all firms moved to buffer against the industry shakeout, it may be that a greater proportion of firms in suboptimal positions integrated downstream to buffer against failure. In addition, we observed that the number of diversifiers moving downstream increased two-fold whereas the number of start-ups moving downstream increased four-fold. In a similar spirit, it may be possible that start-ups are more agile in moving downstream to create buffers against their existing liabilities whereas diversifiers, who already possess integrative capabilities, already possess these buffers or are more inertial in making such changes.

Anecdotal evidence supports the view that firms moved downstream to buffer against industry failure. As the solar shakeout emerged, industry executives and analysts began to talk about the need to "change the business model" to survive in the harsh environment of the shakeout and that "A new downstream focus will define the types of manufacturers able to compete successfully in this evolving market" (Bradford, 2009; Englander, 2009). Although the move downstream required significant changes in capabilities, many firms made this move to protect their existing investments, particularly firms that had established a foothold in technologies that were later revealed to be the non-dominant design. First Solar, may be the most notable example. Although at one point First Solar was the world's largest manufacturer of PV modules, First Solar produced a non-cSi technology (CdTe). As cSi emerged as the dominant design, First Solar increasingly found their module sales challenged by cSi's dominance and in response integrated downstream, a move that allowed it to survive the industry shakeout.

Such moves downstream do appear to have had some impact. First Solar continues to survive and remains a significant presence in the industry, despite producing a technology that did not become the dominant design. Similarly, for other firms, moving downstream appears to have been associated with decreased failure rates, including for firms that entered with the revealed liabilities discussed in the paper. A comparison of the exits for firms that move downstream post-entry suggests that exits for firms moving downstream are much lower than those who stay focused on modules (the exit rates for firms with and without downstream activity at last observation are 36% and 53% respectively). The predominance of firms moving downstream suggests the need for further exploration of antecedents and consequences of post-entry strategy change and migration among levels of a hierarchical technology system, for example from producing a component to producing the entire system.

DISCUSSION

As new industries emerge, diversifying and start-up entrants pursue different technology choices. Technology management literature highlights the role of technology choice on survival (Agarwal and Gort, 2002; Agarwal and Tripsas, 2011; Utterback and Suárez, 1993) and the evolutionary economics literature emphasizes the role of pre-entry capabilities on survival (Agarwal, 1997; Agarwal and Bayus, 2002; Agarwal and Gort, 1996). In this study we bring together these disparate literature streams in strategy that explore the same phenomenon to create a more complete picture of industry evolution by examining the joint effect of technology choice and firm type on survival. Furthermore, we expand the discussion to explore different exit paths and determine when exit results in the dissolution of the firm and its capabilities and when it results in the dissolution of the firm but redeployment of its capabilities through acquisition—an event that has important implications for the acquirer, the acquired and the industry as a whole.

We test our arguments in the context of the global solar PV industry. The analysis provides evidence that choosing the technology that becomes the dominant design or having pre-entry organizational capabilities decrease the likelihood of firm exit. Furthermore, these factors act jointly such that the likelihood for exit is lowest for diversifiers with the dominant design technology, highest for start-ups entering with other technologies, and intermediate for diversifiers entering with other technologies and start-ups entering with dominant design technology. In the analysis of exit paths, we found that diversifying entrants that enter with the technology that becomes the dominant design are least likely to exit via dissolution.

Although scholars have demonstrated the critical impact of technology choice and pre-entry capabilities on survival, by bringing these literatures together we are able to provide a richer explanation of how pre-entry capabilities and technology choices affect firm outcomes and thus a more complete picture of industry evolution. The results are interesting because they go beyond showing the primary impact of established factors on the survival of "winners" to show how firms in many different positions may fare during a shakeout. In addition to showing that the well-established explanations for survival may act jointly, we also show that these factors may also act as buffers, leading to a firm in possession of one fact but not the other to have an intermediate likelihood of exit rather than the greatest likelihood of exit. Thus even firms that choose the "wrong" technology or firms that lack pre-entry organizational capabilities may have significant chances of survival. Such a finding has critical implications for firms that make rational choices during a period of uncertainty and then find themselves in a sub-optimal position after the emergence of a dominant design.

Furthermore, although prior work has provided rich empirical insights into factors affecting exit, this analysis unpacks the type of exit to explore when potentially valuable capabilities of exiting firms are retained versus dissolved. The opportunity to acquire capabilities during a shakeout may be important for survivors since they may be able to purchase valuable capabilities at a discount and thereby fortify their industry position. Furthermore, the fact that some firms exited via acquisition, even if at a discount, sends a signal that even though some firms exited, they nonetheless possessed something of value relative to firms that were dissolved. Our findings suggest that technology choice and pre-entry organizational capabilities also determine whether firms are dissolved or acquired, which underscores their enduring value as explanatory variables and the lines along which new industries consolidate.

The post-hoc analyses reveals aberrations in these patterns that deserve further exploration. First, related capabilities may play a role in exit pathways. Firms with related pre-entry organizational capabilities appear to be less likely to be dissolved. Also, firms with related-pre-entry capabilities in the losing technology were more likely to be acquired during an industry shakeout, which is surprising. These observations deserve further attention. Qualitative observation suggests that many firms in the losing technology still developed valuable capabilities and were acquired in a “roll-ups,” at deep discounts, and put back in to development suggesting that either these technologies serve enduring niches or that there may be a re-emergence of another technology competition someday.

Finally, although scholars have emphasized the role of pre-entry characteristics, firms may also change their strategy after entry (Furr *et al.*, 2012). The limited post-hoc analysis suggests that a surprising number of firms make significant post-entry changes, moving into areas that do not necessarily match their capabilities. Furthermore, those firms that did move downstream appeared to have lower failure rates. Unpacking these observations is beyond the scope of this paper but they deserve exploration in future research, particularly as they provide initial evidence of firms purposefully shifting their position in the technology hierarchy (Murmann and Frenken, 2006), in a pattern contrary to that predicted by industry evolution (Stigler, 1951).

Although there are limitations to this study, including the observation of an industry dependent on manufacturing capabilities and an industry that continues to evolve, nonetheless these results provide insight into how pre-entry characteristics and entry strategies explored by different literature streams jointly impact firm survival, thereby providing a more complete picture of industry evolution. Furthermore, these results suggest the importance of understanding the exit paths taken by firms as well as the ways in which firm strategies evolve after entry.

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Table 1: Descriptive statistics

		Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Exit	0.04	0.20	0.0	1.0	1												
2	cSi	0.69	0.46	0.0	1.0	-0.10	1											
3	Diversifier	0.66	0.47	0.0	1.0	-0.05	0.14	1										
4	Age	6.52	6.26	0.0	35.0	0.08	0.13	0.02	1									
5	Age2	81.77	154.66	0.0	1225.0	0.05	0.13	0.04	0.93	1								
6	Region (China)	0.28	0.45	0.0	1.0	-0.08	0.14	-0.04	-0.07	-0.07	1							
7	Size	5.58	1.23	0.4	8.4	-0.08	0.44	0.03	0.17	0.16	0.32	1						
8	Entry	12.11	9.25	0.0	27.0	-0.12	-0.09	-0.03	-0.13	-0.05	0	-0.08	1					
9	Density	130.57	59.45	1.0	197.0	0.1	-0.08	0.03	-0.01	0	0.13	-0.1	0.45	1				
10	Density2	20581	13482	1.0	38809	0.08	-0.08	0.03	-0.03	-0.01	0.12	-0.09	0.42	0.97	1			
11	Annual prod.	19.88	20.50	0.0	67.6	0.19	0.04	0.08	0.13	0.07	0.14	-0.02	-0.45	0.47	0.41	1		
12	Years before DD	7.71	8.49	0.0	30.0	-0.07	0.14	-0.02	0.64	0.61	-0.18	0.19	-0.22	-0.64	-0.56	-0.46	1	
13	Years after DD	0.27	0.83	0.0	6.0	0.02	0.07	0.09	-0.24	-0.16	-0.03	-0.08	-0.2	0.15	0.12	0.38	-0.3	1

Table 2: Complementary log log, discrete time event history model of firm exit

	1	2	3	4+
Age	5.064 (1.485)***	4.512 (1.173)***	4.457 (1.148)***	4.458 (1.148)***
Age^2	-0.005 (0.003)	-0.004 (0.003)	-0.003 (0.003)	-0.003 (0.003)
Region (China)	-1.826 (0.804)**	-1.421 (0.475)***	-1.418 (0.422)***	-1.432 (0.428)***
Size	-0.471 (0.235)**	-0.200 (0.130)	-0.195 (0.114)*	-0.193 (0.116)*
Entry	0.117 (0.061)*	0.112 (0.060)*	0.113 (0.060)*	0.113 (0.060)*
Density	0.675 (0.193)***	0.636 (0.177)***	0.634 (0.176)***	0.634 (0.176)***
Density^2	-0.002 (0.001)***	-0.002 (0.001)***	-0.002 (0.001)***	-0.002 (0.001)***
Annual production	-0.280 (0.087)***	-0.257 (0.077)***	-0.256 (0.076)***	-0.256 (0.076)***
Years before DD	-4.886 (1.455)***	-4.360 (1.164)***	-4.328 (1.144)***	-4.327 (1.144)***
Years after DD	4.607 (1.379)***	4.283 (1.161)***	4.263 (1.146)***	4.262 (1.146)***
cSi		-1.024 (0.336)***	-0.871 (0.291)***	
Diversifier			-0.732 (0.271)***	
Non-cSi & diversifier				-0.661 (0.354)*
cSi & start-up				-0.789 (0.391)**
cSi & diversifier				-1.600 (0.419)***
N	2,273	2,273	2,273	2,273
Groups	230	230	230	230
Chi squared	28.58	38.10	53.65	53.61
Ll	-287.66	-282.48	-277.04	-276.99

Standard errors in parentheses, * *p*<0.1; ** *p*<0.05; *** *p*<0.01

+ The omitted category of entrants are start-ups that entered with non-cSi technologies. All categories are significantly different from each other (p<0.10) except non-cSi & diversifier and cSi & start-up.

Table 3: Logit model for dissolution (1) over acquisition (0)

	5	6	7	8[+]
Age	-0.734	-0.902	-0.927	-0.885
	(1.619)	(1.161)	(1.175)	(1.151)
Age^2	-0.003	-0.003	-0.003	-0.003
	(0.005)	(0.005)	(0.005)	(0.005)
Region (China)	0.166	0.347	0.322	0.259
	(0.701)	(0.762)	(0.766)	(0.774)
Size	0.161	0.591	0.614	0.669
	(0.469)	(0.514)	(0.521)	(0.539)
Entry	-0.064	-0.085	-0.078	-0.070
	(0.134)	(0.132)	(0.132)	(0.133)
Density	0.474	0.450	0.463	0.481
	(0.367)	(0.366)	(0.368)	(0.370)
$Density^2$	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Annual production	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Years before DD	0.785	0.981	0.993	0.943
	(1.611)	(1.144)	(1.157)	(1.131)
Years after DD	-1.089	-1.113	-1.117	-1.055
	(1.651)	(1.200)	(1.211)	(1.186)
cSi		-1.538	-1.532	
		(0.516)***	(0.517)***	
Diversifier			-0.247	
			(0.505)	
Non-cSi & diversifier				0.223
				(0.693)
cSi & start-up				-1.000
				(0.737)
cSi & diversifier				-1.759
				(0.712)**
N	104	104	104	104
Chi^2	24.31	33.82	34.06	35.05
Ll	-58.00	-53.24	-53.12	-52.63

Standard errors in parentheses, * p<0.1; ** p<0.05; *** p<0.01

[+] The omitted category of entrants are start-ups that entered with non-cSi technologies. Only cSi & diversifiers is significantly different from other categories.

Table 4: Post hoc analysis: Effect of pre-entry related organizational capabilities (diversifiers)/founder knowledge (start-ups) on exit and mode of exit

	9 (dissolution)	10 (dissolution, diversifier only)	11 (dissolution, start-up only)	12 (dissolution, non-cSi only)
Age	-1.405 (1.145)	-2.046 (2.467)	-0.357 (1.517)	2.632 (386.494)
Age^2	-0.001 (0.006)	-0.001 (0.009)	0.001 (0.024)	-0.002 (0.012)
Region (China)	0.460 (0.837)	-0.035 (1.525)	0.092 (1.219)	
Size	0.599 (0.546)	0.720 (0.667)	0.242 (0.981)	
Entry	-0.111 (0.139)	-0.313 (0.242)	0.098 (0.220)	0.157 (14.583)
Density	0.527 (0.388)	0.269 (0.630)	0.796 (0.624)	0.931 (34.434)
$Density^2$	-0.002 (0.001)	-0.001 (0.002)	-0.002 (0.002)	-0.003 (0.073)
Annual production	0.000 (0.000)*	0.000 (0.000)	0.000 (0.000)	-0.000 (0.029)
Years before DD	1.367 (1.113)	2.026 (2.424)	0.332 (1.516)	-2.651 (386.494)
Years after DD	-1.702 (1.193)	-2.477 (2.503)	-0.207 (1.719)	2.611 (386.495)
cSi	-1.257 (0.546)**	-1.763 (0.870)**	-0.790 (0.785)	
Diversifier	-0.134 (0.533)			0.420 (0.765)
Related	-1.553 (0.576)***	-2.040 (0.912)**	-1.487 (0.975)	-1.598 (0.804)**
N	104	58	46	49†
Chi^2	33.48	13.91	12.78	42.14
Ll	-22.91	-23.35	-23.79	-49.08

Standard errors in parentheses, * p<0.1; ** p<0.05; *** p<0.01

† Note that 6 observations dropped from the analysis

Table 5: Solar PV module manufacturers' integration into downstream activity of designing and installing Solar PV electricity systems.

Firm Type	Total Entrants	Downstream at Founding	Downstream at Last Observation	Percent Change		Firms Exits (All)	Firm Exits (Downstream at Last Observation)
All Firms	239	40	131	228%		104	47
cSi Firms	159	32	99	209%		49	28
Non-cSi Firms	80	8	32	300%		55	19
Diversifiers	169	32	89	178%		58	27
Start-ups	179	8	42	425%		46	20

Figure 1: Framework for analyzing firm-technology choice outcomes

		Technology Choice	
		Non-Dominant Design	Dominant Design
Pre-entry Organizational Capabilities	Diversifier	Quadrant 3: Intermediate likelihood of exit / dissolution	Quadrant 4: Lowest likelihood of exit / dissolution
	Start-up	Quadrant 1: Highest likelihood of exit / dissolution	Quadrant 2: Intermediate likelihood of exit / dissolution

Figure 2: Solar PV module manufacturer entry and exit

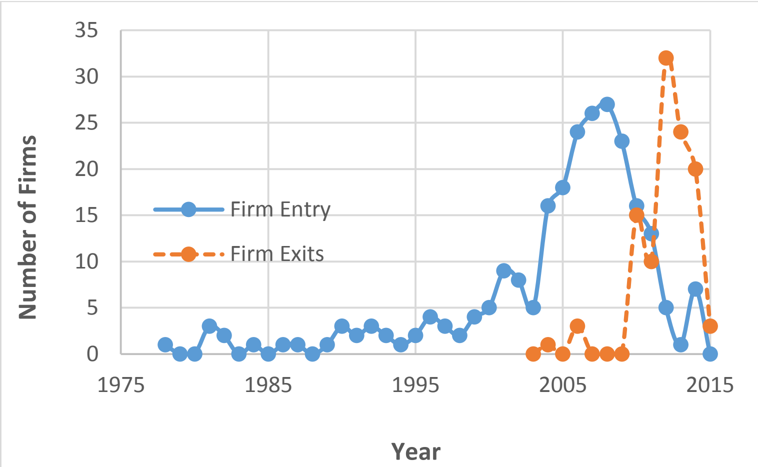

Figure 3: Solar PV module manufacturer entry and exit by technology

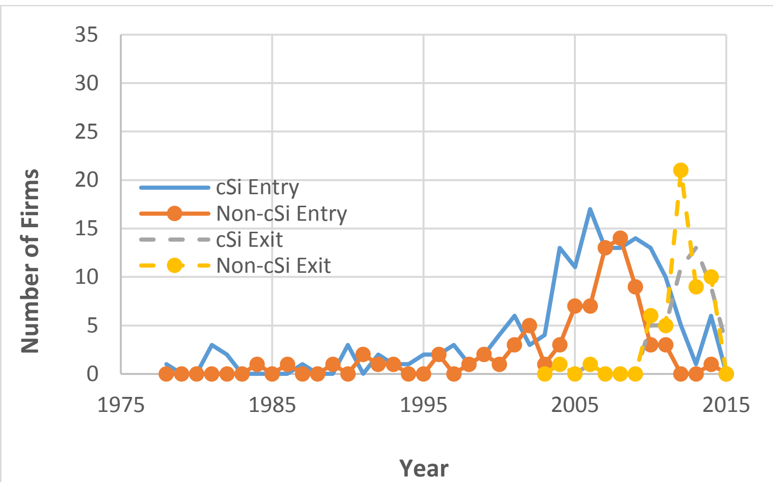

Figure 4: Solar PV module manufacturer entry and exit by pre-entry capabilities