Entrepreneurial Ventures' Market Choices: Essays from the Solar Photovoltaic Industry

Mara Guerra

Under the direction of Prof. Bart Clarysse and Dr. Anu Wadhwa

A dissertation submitted in partial fulfillment

of the requirements for the Degree of Doctor of Philosophy

at Imperial College London

Imperial College Business School

Department of Management and Entrepreneurship

London, United Kingdom

2020

STATEMENT OF ORIGINALITY

This dissertation represents my own work. All the material and work that is not my own has been properly acknowledged. Acknowledgment of all the work that is not my own has been made in the text.

COPYRIGHT DECLARATION

To my parents

ACKNOWLEDGMENTS

Coming into the PhD program, I was certainty not aware of what was ahead of me. During this long journey and its ups and downs, I was fortunate to always be in good the company and surrounded by people who have inspired me and enriched my life, This dissertation would have not been possible without the continuous support of my supervisors, my family and my friends. I thank you all.

I would like to express my deepest gratitude to my supervisors, Anu Wadhwa and Bart Clarysse for their guidance, support and encouragement. You have motivated me and pushed me to be a better researcher. I thank you for the incredible opportunities you gave me throughout these years. Many thanks also to my examiners, Paola Criscuolo and Mahka Moeen, for your invaluable and detailed feedback.

My deepest gratitude goes to my family for supporting me in my decision to pursue a PhD and during these many years. To my Father Ottorino and my Mother Loredana, for teaching me the values of kindness, dedication and hard work. You have always been there for me, for the big and the small things. Thank you for your sacrifices and never-ending support. To my brother Mauro for the much-needed comic relief, the funny dinners and being the cool brother that you are. I have a big, loud, Italian family and I wouldn't want it any other way. Thank you to all for rooting for me from afar.

During the PhD, I was blessed to meet many people that I now call friends. Thank you to Krystal, for always being partners in crime, to Cleo, our lunches and coffees together have always been a source of joy, even in the worst days, to Francesca for joining our little Italian club and being an instant friend. To Esma, for being a delight and always offering a kind word. To Lin, for the inspiring conversations and the shared dinners. To Giada, for the honesty and for bringing the Italian flair to the conversation. To Amy, for recognizing each other as similar souls both research-wise and personality-wise. To Lisa, Maxine, Marine, Laurens, Dheeya, Yuting and Christa for being amazing colleagues. I am honored to call all of you friends and will always cherish our adventures together. I hope there will be many more.

Thank you to my friends back home for the continuous support and for always being interested in what I was up to: Fjore, Andreas, Martina, Marianna, Cate, Stella, Laura, Marina and Franca. I know you’re always there for me.

I would like to thank Katherine Campbell, Catherine Lester and Pamela Monteith for being incredible PhD program coordinators, for sharing my joys in good times and their kindness in bad times. I would also like to thank Rachel Jury for her invaluable help and always making sure I did things in time.

Finally, I gratefully acknowledge the financial support of the Imperial College London President’s PhD Scholarship and Business School Graduate Teaching Assistant Scholarship.

ABSTRACT

This dissertation seeks to understand how entrepreneurial ventures make technology commercialization decisions on the product market and under conditions of demand heterogeneity Furthermore, it seeks to understand how entrepreneurial strategies unfold and their consequence for ventures and industry alike. To this end, I carry out three empirical studies of the solar photovoltaic industry. The first study explores the drivers of the decision to enter a niche product market. Despite the key role of niche markets for a disruptive strategy, we still know little about which ventures make this choice. I characterise mainstream and niche markets in terms of the different commercialization challenges to be encountered in each one of them. I find empirical support for the role of prior experience on having preferences for different commercialization challenges, underscoring the role of cognition on the decision to enter niche markets. In the second study, I explore the factors that lead ventures to enter markets with low technology-market fit. Grounding the commercialization journey of start-ups in the technology-to-market linking process, I study how industry-level factors can make the process cognitively more or less taxing. I find empirical support for the idea that increasing capital availability creates a bias that leads ventures towards poorly fitting markets, despite their belief to be making a promising choice. Moreover, I show that the more choices were previously made by other ventures, the easier it is to choose highly fitting markets. The third study focuses on how the strategies of dominant firms unfold over time and affect venture-level and industry-level outcomes. More specifically, I identify two strategies – a technology-driven one and a paradigm-driven one – that are critical to move the industry to early commercialization but set up conditions that prevent further uncertainty reduction to reach sales take-off and maturity, condemning the industry to a slow retrenchment.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Entrepreneurial ventures are considered to be the engine of technological change and industry emergence (Schumpeter, 1934). Integration into the product market is a key pathway to commercialize a technology, favored by entrepreneurial ventures (Peters & Thiel, 2016) who often see commercialization on the product market and the creation of a new industry as the hallmark of entrepreneurship and success.

Recent research has seen a rise in interest in the strategic choices of entrepreneurial ventures (Furr, 2019; Hannah & Eisenhardt, 2018; McDonald & Gao, 2019; Zuzul & Tripsas; 2019), including the choice of which market to enter (Shermon & Moeen, 2020). Much of what we know about ventures' decisions to commercialize on the product market comes from the literature on the market entry decision that examines integration into the product market as an alternative to licensing (Teece, 1986; Gans & Stern, 2003).

Existing scholarship has given us rich insights into the role of the intellectual property regime and complementary assets on the commercialization decision (Teece, 1986; Gans & Stern, 2003). The predominant view is that the lower the cost of assembling the necessary complementary assets to bring the technology to market, the more attractive commercialization on the product market becomes (Colombo, Grilli, & Piva, 2006; Rothaermel & Hill, 2005). This is especially true when the intellectual property (IP) regime is not sufficiently strong to allow firms to appropriate the returns from their technology via licensing (Arora, Fosfuri, & Gambardella, 2001; Gans & Stern, 2010; Teece, 1986).

When applied to entrepreneurial ventures, extant work on the technology commercialization decision suffers from some shortcomings. Evidence shows that entrepreneurial ventures have a strong preference for commercialization on the product market (Peters & Thiel, 2016). Moreover, even when licensing is their preferred pathway to commercialization, they often need to integrate into the product market first to prove their technology (Marx, Gans & Hsu, 2014). Thus, when entrepreneurial ventures make their technology commercialization choice, they may not consider integration into the product market and licensing at the same time, but they make this decision sequentially and integration into the product market is their preferred choice.

Since the decision to integrate into the product market takes center stage for entrepreneurial ventures, we need a more fine-grained understanding of the factors affecting product market choices. In this dissertation, I explore two factors that play a role when commercialization is focused on the product market.

First, I explore the role of demand heterogeneity (Priem, Li & Carr, 2012; Adner & Levinthal, 2001). Extant work on the technology commercialization decision has equated product market with industry and has paid limited attention to differences in the types of markets and to how demand-side factors (Priem et al., 2012), such as the role of customer preferences (Adner & Levinthal, 2001), affect the commercialization decision among different product markets. For entrepreneurial entrants, the existence of multiple sub-markets creates both opportunities and complexities. On the one hand, it creates the opportunity for them to position in product markets that fit their technological trajectory and their competences (Adner & Snow, 2010). It also gives them the opportunity to gain a favorable foothold to disrupt the industry by choosing a niche product market (Christensen, 1997). On the other hand, to position favorably, ventures need to understand a more complex environment including the characteristics and competitive dynamics within multiple sub-markets, the resources needed in each one of them and how customers in each sub-market evaluate technologies. Thus, it increases the likelihood that ventures may choose markets in which their technology is not valued or where they will face intense competition from incumbents.

Second, I explore the key role of entrepreneurial cognition as a driver of decisions related to the product market. Extant work has focused on market structure and complementary assets as an explanation for the market entry decision but has neglected the role of entrepreneurial cognition on market entry decisions. Yet, a long tradition in the entrepreneurship literature has highlighted the key role of cognition for decision making (Fern, Cardinal & O'Neill, 2012; Furr, Cavaretta & Garg, 2012; Gruber, MacMillan & Thompson, 2008; 2013).

Research on cognition highlights the key role of the manager in interpreting the ambiguity of the environment to make decisions (Daft & Weick, 1984: Gavetti & Levinthal, 2000; Ocasio, 1997). In fact, the way in which managers sort through information, what cues they pay attention to and how they interpret such cues to make decisions is critical to their ability to respond to the environment.

Extant work on entrepreneurial cognition has highlighted the key role of the team of executives leading the ventures in steering the venture's strategy (Beckman, 2006; Beckman & Burton, 2008; Eisenhardt, 1989). Existing work in this stream of research has underscored the role of prior experience of the team leading the venture as the key driver of entrepreneurial cognition (Fern et al., 2012; Furr et al, 2012: Furr, 2019; Gruber et al., 2008:2013). In fact, experience gained through employment before founding or joining the venture has been found to crucially shape the venture executive's knowledge structures which, in turn, affect what they pay attention to and how they interpret that information, i.e. cognition.

The role of prior experience in shaping cognition and decision making is pervasive in the life of entrepreneurial ventures. At the very beginning of the life of a venture, prior research has found that pre-entry experience influences processes such as the formation of entrepreneurial beliefs, the identification of opportunities (Shane, 2000; Gregoire & Shepherd, 2012; Gruber et al., 2008; 2013) and the resources chosen to pursue them (Fern et al., 2012). The role played by prior experience on cognition continues as the venture develops. In fact, it plays a fundamental role in the ability of ventures to adapt their technology to the changing environment of emerging industries (Furr et al., 2012; Furr, 2019).

These studies point to the importance of entrepreneurial cognition to study entrepreneurial choices. When it comes to the choice of markets, existing research on cognition has found that the existing knowledge structures, as influenced by prior experience, of the venture team constrains the choices that a venture can possibly make. In fact, ventures have been found to choose the same market over and over again and to use the same resources that they are familiar with (Fern et al., 2012, Shane, 2000). Thus, existing work gives us initial evidence that entrepreneurial cognition may also play a role for decisions regarding the commercialization of technologies on the product market under conditions of demand heterogeneity, making entrepreneurial cognition an ideal candidate explanation for heterogeneity in decisions regarding the pursuit of different product markets and especially the decision to enter different *types* of product markets such as mainstream vs. niche markets.

Extant work has also largely explored only the role played by factors internal to the venture on entrepreneurial cognition. Much less attention has been paid to the role that factors external to the ventures can play or to the interplay between internal and external factors. In fact, only recent research has begun to explore how factors other than prior experience affects cognition. For example, Pahnke, Katila & Eisenhardt (2015) have found that the logics of the venture's investors affect the types of innovation pursued. More generally, Benner & Tripsas (2012) highlighted the role of choices of other firms on the focal firm's cognition. Given that the cognitive processes involved in choosing a product market for technology commercialization depend on the knowledge of the existence of markets, further work on external factors that either reveal or hide the existence of markets or make information about them more prominent or on the interplay between internal and external factors both provide a fruitful avenue to extend what we know on entrepreneurial cognition.

Finally, given the key role of product markets for entrepreneurial ventures, we need a more fine-grained understanding of how strategies on the product market unfold over time and of their consequences. While existing work has given us rich insight on the antecedents of the market entry decision, we still know relatively little about what happens after this decision has been made and its subsequent consequences for both the ventures themselves and the industry.

This dissertation addresses these shortcomings and seeks to understand the cognitive underpinnings of the market entry choice and technology-to-market linking under conditions of demand heterogeneity. Moreover, it seeks to address the consequences for ventures and the industry of the strategies unfolding on the product market. To this end, I carry out three empirical studies. Study 1 examines the cognitive drivers of the decision to commercialize a technology on niche product markets. Study 2 delves deeper into the role of demand heterogeneity on the technology-to-market linking process and explores how cognition can affect the decision to enter product markets where the technology is not valued (Adner & Levinthal, 2001). Study 3 examines the strategies implemented on the product market by technology dominant ventures and their consequences for the ventures and the industry.

The three studies are set in the solar photovoltaic (PV) industry. The solar PV industry is dedicated to the development of technologies that transform sunlight into electricity. On the demand side, the industry is segmented into multiple sub-markets around different applications for solar technologies ranging from traditional applications, such as rooftop systems, to disruptive ones, such as building-integrated photovoltaics or solar fabric. From a cognitive perspective, a wide variety of ventures entered the industry, characterized by different pre-entry experiences that influence their cognition. Thus, the ventures varied widely in their cognition and subsequent decision making. These characteristics make the solar PV industry an ideal context to study commercialization on the product market and the role of cognition on the decisions made by ventures. In the next section, I give an overview of the three studies.

The first study of this dissertation looks at how cognition of the venture teams, as influenced by their pre-entry experience, affects the decision to enter a niche product market (Christensen, 1997; Danneels, 2004). The choice of niche product market is deemed consequential by the literature on disruption (Christensen, 1997) because it gives ventures a foothold into the industry positioning for disruption. Despite the importance of this decision, we still know little about who decides to pursue a disruptive strategy.

I first challenge the assumption that product market is synonymous with industry and that the commercialization challenges faced by ventures on the product market are the same everywhere within the industry. This assumption ignores the reality that industries can be further partitioned into sub-markets based on a number of different criteria such as products and services offered, customers targeted, or the technologies used (Klepper & Thompson, 2006) and that different types of markets present different commercialization challenges.

The literature on disruption has conceptualized the difference between mainstream and niche product markets in terms of competition (Christensen, 1997). I complement this definition by also differentiating the two markets based on availability and consolidation of market-specific complementary assets. The differences in the state of complementary assets in these markets present unique challenges for ventures entering each type of market: mainstream markets are characterized by intense technological challenges, while niche markets are characterized by intense challenges in the downstream part of the value chain.

I use a cognitive lens to explain why ventures choose niche product markets and argue that prior experience of the venture teams primes them to recognize and favor different types of challenges (Fern et al., 2012; Gavetti and Rivkin, 2007, Ocasio, 1997). The results show that venture teams' prior technical experience leads them away from niche product markets and into markets where commercialization on the product market is more difficult. They also show that prior experience in marketing roles or as an entrepreneur will lead ventures towards these unserved spaces. Finally, I explore the contingent role of having gained the different types of prior experience in the focal industry on choosing niche markets.

This study contributes to the literature on disruption by unpacking the mechanisms that lead ventures toward or away from niche markets. I show that ventures commercializing potentially disruptive technologies do not always choose niche markets, thus, contributing an explanation for why disruption may not happen. The results also inform the literature on market entry by showing that the commercialization challenges faced by entrepreneurial ventures differ between mainstream and niche markets. The findings also demonstrate that a group of ventures will enter markets where complementary assets are consolidated (theorized to be mainstream markets) and make choices that cannot be explained by market structure. Thus, I extend this literature by highlighting the role of cognitive factors on market entry choices.

The second study of this dissertation examines more closely the role of demand heterogeneity on the commercialization process and explores the factors that lead ventures to enter markets with poor technology-market fit. Prior literature has long identified that choosing the wrong market carries many risks for entrepreneurial ventures (Molner, Prabhu & Yadav, 2019; Shane, 2004), yet we still know little about why ventures make this choice.

Existing work on technology commercialization of entrepreneurial ventures relies on the technology-to-market linking process – a process of market search that involves the identification and evaluation of potential technology-market pairs (Gregoire & Shepherd, 2012; Gruber, MacMillan & Thompson, 2008). Extant work, however, has largely focused on the first step of technology-market pairs identification and has linked more markets identified to superior commercialization outcomes for the venture (Gruber et al., 2008; 2013). Linking larger opportunity sets to positive outcomes seems to suggest that all markets are equally promising. Yet, not all markets evaluate the same technology in the same way (Adner & Levinthal, 2001, Priem et al., 2012) and we don't know whether these positive outcomes were reached only after trying several markets. Thus, in light of differential technology evaluation, the second step of technology-market pair evaluation gains importance.

In this study, I explore the role of industry-level factors, i.e. factors external to the ventures, and of the interplay between internal and external factors on the likelihood that ventures choose markets with poor technology-market fit. While most of extant work has exclusively focused on the role of internal factors such as knowledge endowments on the technology-to-market linking process (Gregoire & Shepherd, 2012; Gruber et al., 2008; Gruber et al., 2013; Shane, 2000), the cognition of ventures is likely influenced also by external factors that affect the availability and quality of information. This is especially true for decisions regarding products and markets (Benner & Tripsas, 2012). As the evaluation of markets critically depends on information about demand, industry-level factors that affect the availability and quality of this information play a crucial role for the second step of the linking process. I argue that industry-level factors can hide or reveal the information about the demand landscape and, thus, they affect how cognitively taxing the technology-market linking process and especially evaluation is.

At the same time, cognitive processes such as the one involved in identifying the right market for the technology also depends on how ventures interpret this demand side information. For this reason, I explore the intersection between industry-level factors and ventures' characteristics that can affect how capable ventures are of addressing the cognitive load involved in the technology-market linking process.

I find that increasing prior capital availability shines light only on parts of the demand landscape and hides information about other parts, which creates a "hyped-up" demand landscape and increases entry into poorly fitting markets. I also find that industry spinouts have superior cognitive ability that help them see past the cognitive bias of the "hyped-up" demand landscape and make more objective choices in times of increasing capital availability.

The results of the study inform the literature on technology commercialization of entrepreneurial ventures, entrepreneurial cognition and venture capital. I show that the decision to enter poorly fitting markets is favored by a cognitive bias at the industry level created by increasing prior capital availability. Thus, I show that entry into markets that do not fit is not a counterintuitive choice as one would think. I also underscore the role of factors external to the venture in making cognitive processes more or less taxing for ventures. I illuminate a cognitive advantage for industry spinouts that complement existing findings of superior capabilities for these ventures. Finally, I illuminate the role of venture capital on ventures other than the investees.

Finally, the last study of this dissertation explores the consequences of entrepreneurial strategies. This study examines how the strategies of dominant ventures unfold over time and links these strategies to outcomes for the ventures as well as the industry. More specifically, it explores how the strategies developed by the dominant ventures during the pre-commercialization phase affect the ventures' outcomes and industry evolution in the post-commercialization phase, and generate the conditions that prevent an industry to reach sales take-off and successfully emerge (Agarwal & Bayus, 2002). While current work on industry emergence has given us rich insights into the factors and processes that help industries to successfully emerge, we know far less on what prevents industries from reaching sales take-off (Moeen, Agarwal & Shah, 2020). Moreover, existing scholarship has only recently began to explore how the decisions taken during the pre-commercialization phase affect the post-commercialization phase (Moeen, 2017; Roy, Lampert & Sarkar, 2019).

The findings from this qualitative study of the emerging thin film solar industry show that thin film was dominated by few ventures and that these ventures pursued two contrasting strategies, which I label as *technology-driven* and *paradigm-driven strategies*. Technology-driven ventures anchored the opportunity to the scientific breakthrough that enabled thin film and framed the technology in terms of competition with the old technology with the goal to overtake it (Agarwal, Moeen & Shah, 2017; Christensen, 1997). As a consequence, they pursued a strategy favoring individual actions dedicated to resolving technological uncertainty, a "do it yourself" attitude with little collaboration, well-defined and aggressive development roadmaps and showing technical strength. In contrast, paradigm-driven ventures anchored the opportunity to the grand challenge of climate change and framed the technology in terms of a new paradigm competing with the existing paradigm of electricity production based on fossil fuels (Agarwal et al., 2017; Ferraro, Etzion, & Gehman, 2015). Accordingly, their strategy included widespread collaboration to address multiple dimensions of uncertainty, a "borrow from others" attitude that led them to aggregate knowledge from multiple sources and collective actions, such as lobbying, to gain favor for the industry.

The findings also show that such cognitive framing and the ensuing strategies created the dynamics that prevented the industry from successfully emerging. More specifically, the mismatch between what the strategies addressed and the main sources of uncertainty in the industry during early commercialization led to a slowdown in uncertainty reduction over time. Additionally, during early commercialization, the two strategies began to address similar sources of uncertainty but created conditions that led to the questioning of the existing knowledge base. Over time, the strategies implemented by the ventures led to the inability to aggregate knowledge and the questioning of the industry's potential. Together, these factors prevented the development of the industry's infrastructure and the creation of new knowledge.

The findings from the third study illuminate the heterogeneity in technology ventures and trace it back to the cognition of these ventures. Thus, they complement existing work that trace heterogeneity of entrepreneurial ventures to their knowledge and capability sources (Agarwal & Shah, 2014). As much of prior work has sampled on successful cases of industry emergence, we are familiar with the factors that help industries transition to maturity, but we still know relatively little of the factors preventing this outcome. The findings from this study shed some initial light on these factors.

The dissertation is organized as follows: chapter 2 presents an overview of the empirical context – the solar PV industry, chapter 3 presents study 1, chapter 4 presents study 2, chapter 5 presents study 3. Finally, chapter 6 offers concluding remarks.

2. THE SOLAR PHOTOVOLTAIC INDUSTRY

The solar photovoltaic (PV) industry aims to develop and commercialize technologies that transform solar light into electricity. The idea of using the sun as a source of energy is quite intuitive. Yet, the scientific discovery that enabled the use of solar light to generate electricity took place only in the 19th century. In 1839, the French physicist Edmond Becquerel discovered what is now known as the "photovoltaic effect", i.e. that certain materials interact with sunlight when exposed to solar radiation. This interaction makes electrons move, creating a flow of electric current. This effect stands at the core of the solar photovoltaic industry.

This scientific breakthrough remained largely unused for decades until scientists at Bell Laboratories developed the first modern solar cell based on silicon in 1954. This led to a significant reinvention of solar energy and resulted in a science-intensive industry with high capital requirements (Jones & Bouamane, 2012). In the decades that followed, research centers and universities around the world kept tinkering around solar cells to improve their performance but for the longest time, solar cells were reserved for partial use in satellites or demonstrative use, but never found their way out of the lab for commercial use.

The commercial use of solar PV was largely constrained by the physical properties of silicon that made solar energy prohibitively expensive and limited its deployability (i.e. where it could be used). To this end, research into new types of semiconductor materials was financed starting from the 70s. The goal was to address the limits of cost and deployability to make solar energy more cost-effective and more available. The end goal was to stimulate solar energy's competitiveness with traditional sources of energy based on fossil fuels. Over time, these technologies took the name of thin film technologies (second and third generation technologies) because they enabled the creation of solar cells that are thin and flexible rather than bulky, heavy and fragile.

While silicon was introduced earlier and is effectively the technology that gave rise to the modern solar PV industry, silicon-based and thin film technologies developed in parallel starting from the late 90s/early 2000s when they all received much impetus due to the increasing concern for climate change and ensuing interest in renewable energy sources.

The solar PV industry makes for an interesting research context from both the technological and demand side. From the technological side, the development of multiple technologies which differed in their performance along several performance attributes created significant uncertainty about which technology would succeed and become the dominant design. This led to intense technological competition among the generations to win the technological race (Ardani & Margolis, 2011; Bradford, 2006).

From the demand side, the industry is segmented into multiple markets around applications in which to use solar PV cells. In the following sections, I discuss more in details the three technological generations and the value chain of solar PV technologies and the market segment existing in the industry and the complementary assets needed for commercialization in each one of them.

2.1. PHOTOVOLTAICS TECHNOLOGIES AND THE VALUE CHAIN

The solar PV industry is characterized by three technology generations. Each technology generation includes several technology variants. The three generations rely on different knowledge bases both in terms of manufacturing methods and of semiconductor compounds. As a consequence, each generation performs differently along different performance attributes. Figure 1 shows a timeline of the solar PV industry and provides an overview of the three technology generations and key events for each one of them.

			1950s	1960s	1970s	1980s	1990s	2000s	2010s
First generation	Key events		1954 - Bell Labs: first silicon-based cell			1982 - commercialization			
	Average efficiency*	monocrystalline					23.76%	24.73%	25.66%
		polycrystralline					18.19%	20.11%	20.92%
Second generation	Key events				1972 - Uni. Of Delaware: First lab to study thin film solar		1990 - commercialization		2014: CIGS overtake silicon efficiency
	Average efficiency*	CIGS					15.50%	18.64%	20.61%
		CdTE					15.88%	16.47%	19.18%
Third generation	Key events					Investment into new semiconductor materials for thin film solar	1993 - commercialization		
	Average efficiency*	dye sensitized					6.50%	9.30%	11.53%
		Organic polymer					n.a.	4.43%	9.94%

*source: Solar efficiency tables 1-52, Progress in Photovoltaics: Research and Applications, 1993-2018. Data available from 1993.

Figure 2-1 Timeline of solar PV industry and overview of technology generations

2.1.1. First-generation PV

The first generation of solar PV technologies include silicon-based technologies. This was the first technology to be introduced and is the technology that gave rise to the modern solar PV industry. To produce a silicon-based solar cell, manufacturers rely on silicon ingots that are then sliced into wafers. These silicon wafers are doped, wired and coated to produce solar cells that are then assembled into solar panels. From the point of view of the knowledge base necessary for manufacturing, ventures developing silicon-based PV cells can draw from the knowledge developed in other industries, especially semiconductors and electronics. Not only can they borrow the manufacturing equipment, but they can also borrow the process for growing silicon ingots.

Solar cells based on silicon offer high efficiency. Until the late 2000s, they were the cells offering the highest efficiency available, yet they were approached by second-generation technologies starting from 2010. From 2014, some of the variants in the second generation were able to overtake cells based on polysilicon in terms of efficiency. The manufacturing of silicon solar cells requires large quantities of high purity silicon. As a consequence, their cost is highly dependent on the price of this semiconductor material. The price of high purity silicon was very high until 2011 when it dropped significantly due to an increase in the supply of high purity silicon generated by entry into the upstream part of silicon value chain. Thus, nowadays silicon-based cells offer high efficiency and low costs.

Despite the efficiency and cost advantage, silicon solar cells suffer from some limitations due to the physical properties of silicon. The manufacturing process based on slicing and doping means that first-generation cells are rigid, heavy and fragile. These characteristics limit the deployability of solar energy and make cells based on first-generation technologies suitable only for some market segments.

2.1.2. Second-generation PV

The second generation of solar PV technologies emerged during the 1970s with the goal of substituting silicon with different semiconductor compounds. These technologies differ from the first generation based on the manufacturing methods and the semiconductor compounds used. From the point of view of manufacturing, they are manufactured in a substantially different way than silicon-based technologies. Rather than relying on growing and slicing ingots, second-generation technologies use deposition or printing processes. This means that the semiconductor compounds can be deposited or printed in thin layers on different substrates such as plastic or metal. From the point of view of the semiconductor materials, PV technologies in the second generation most often rely on compounds of semiconductor materials rather than a unique semiconductor. The most widely used compounds in this generation are based on copper indium gallium selenide (CIGS) or Cadmium telluride (CdTe).

The knowledge base of the second-generation technologies differs vastly from the one used in first-generation technologies. Unlike ventures developing silicon solar cells, ventures developing these technology variants could not rely on the knowledge previously developed in the semiconductor or electronics industries. Instead, they could look at the printing industry for inspiration for their manufacturing process. Yet, most of the knowledge base had to be developed from scratch. How to optimize the combination of semiconductor materials, how to optimize printing or deposition for the specific compound, which equipment was necessary for reliable scale up were all questions that had no answers.

As the semiconductor materials are deposited or printed on films of plastic or metal, second-generation cells are extremely thin and flexible, making them a lighter and more versatile option than silicon-based cells. Before the drop in silicon price of 2011, these cells promised to be a much lower cost alternative to silicon. This was counterbalanced by lower efficiencies until 2014. Nowadays, second-generation technologies are in decline and are still considered a promising option only for some markets that are still in their infancy.

2.1.3. Third-generation PV

Third-generation technologies are the latest thin film generation. In fact, they rely on similar manufacturing methods as the second generation but make use of new classes of semiconductor materials such as nanomaterials, e.g. polymers and organic materials, or those that are abundant and environmentally friendly, e.g. Copper Zinc Tin Sulfide (CZTS).

Some of the technical knowledge base for this generation is shared with the second generation of solar PV. In fact, by relying on similar manufacturing methods, some of the manufacturing knowledge developed for second-generation technologies can also be used for third-generation PV. However, ventures developing third-generation PV need to develop the knowledge related to the semiconductor compounds and how to scale them successfully.

At the time of writing, most of the technologies in this generation have not yet reached widespread commercial success and large-scale production. If large scale production can be achieved, the third generation of PV technologies would provide the lowest cost alternative in the market. Additionally, the technologies included in the third generation perform extremely well in terms of transparency, design choice (the color can be chosen) and flexibility. However, their performance in terms of efficiency is still lacking despite progress in the past years. Table 3 in the Appendix gives an overview of the three technologies and their performance along with key attributes.

2.1.4. Value chain

In this dissertation, I study the decisions of ventures that entered the solar PV industry to commercialize solar PV cell technologies, i.e. they are placed midstream in the value chain. This categorization is in line with the categorization used by previous studies on the solar PV industry (Furr & Kapoor, 2017; Hannah & Eisenhardt, 2018; Kapoor & Furr, 2015).

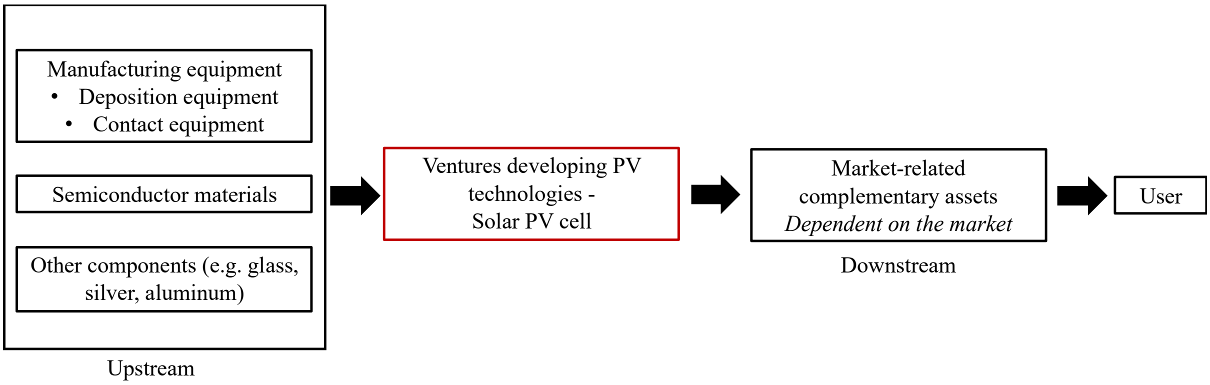
In this section, I discuss the upstream part of the value chain and the complementary assets necessary for the manufacturing of solar cells. The complementary assets necessary to bring the solar PV cell to market differ based on the market that the venture decides to pursue. I will discuss the downstream complementary assets in more details in the next sections.

Figure 2 illustrates the general value chain in solar PV. Panel A highlights the state of upstream complementary assets for the first technology generation, while Panel B highlights upstream complementary assets for the second and third generations. These two generations are discussed together as they share some similarities in the manufacturing methods and have similar upstream complementary assets.

The two most important complementary assets for manufacturing are deposition equipment and contact equipment. These two types of manufacturing equipment are necessary to scale up the technology and manufacture it commercially (Kapoor & Furr, 2015). There are important differences in the availability of these two types of equipment between the first-generation technologies (Panel A) and the other two generations (Panel B). In the case of first-generation technologies, these two types of manufacturing equipment were largely available due to spillover from the semiconductor industry. This means that the manufacturing equipment could be acquired almost off the shelf. The situation is quite different for the second and third generations. Availability of upstream assets was much more limited (Kapoor & Furr, 2015). Ventures developing these technology generations had to develop much of this equipment in-house (see dashed line in Panel B), which led to high investments to develop the manufacturing knowledge base.

Another important component of a solar PV cell is the semiconductor material. Ventures developing silicon-based technologies (first generation) can rely on a well-developed value chain for silicon. For ventures developing thin film technologies (second and third generations), the material can be licensed in from universities or developed in-house. For the second and third generations, the specific semiconductor compound was mostly developed in-house (hence, the dashed line in Panel B) because it was a source of competitive advantage. To conclude, ventures developing second and third-generation technologies could not rely on a well-developed upstream value chain and had to develop significant manufacturing knowledge to bring their technology to market and scale them.

Panel A: Value chain for first-generation technologies (silicon-based)



Panel B: Value chain for second and third-generation technologies (thin film)

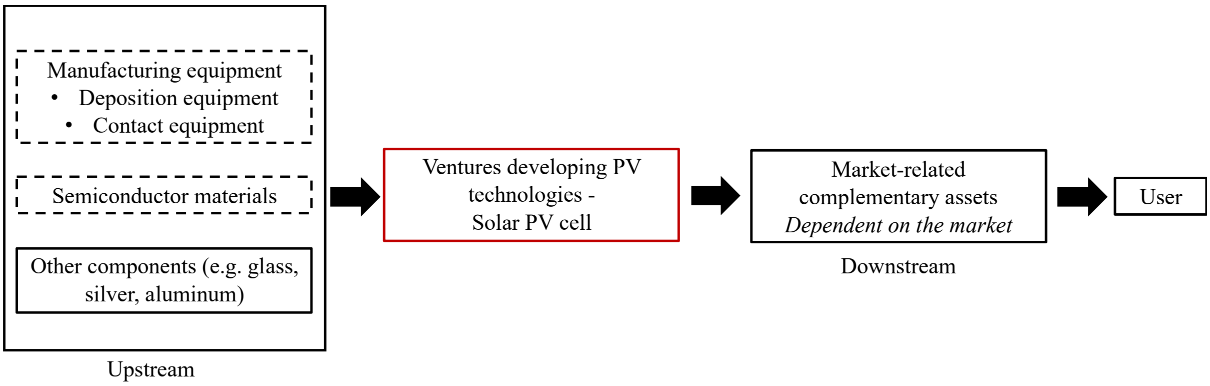


Figure 2-2 Overall value chain in the solar PV industry

2.2. MARKETS AND COMPLEMENTARY ASSETS

From the demand point of view, the solar PV industry offers a unique opportunity to study product market decisions of ventures. In fact, the industry can be segmented into several sub-markets around the specific product in which solar cells are integrated.

Throughout the dissertation, I define markets as specialized product clusters that can be differentiated from others along dimensions such as the product or service offered, the customers targeted or the technology used, thus following prior literature studying segmented industries (Klepper & Thompson, 2006; Uzunca, 2018). Given my interest in market positioning and in the nuances of product markets due to demand heterogeneity, I define sub-markets around the products they offer. This focus on markets around products follow prior research on market positioning (Adner & Snow, 2010; de Figueiredo & Silverman, 2007).

The qualitative work I conducted led to the identification of 19 specific sub-markets around different applications in the industry. These 19 specific markets can be classified into four categories: rooftop systems, ground-mounted systems, building-integrated photovoltaic (BIPV) and integrated products. BIPV and integrated products have higher variety of specific sub-markets. For example, BIPV includes applications such as solar tiles and solar glass. Integrated products includes specific applications such as chargers, solar fabric and aerospace applications. Additionally, the four market categories can be further classified as mainstream or niche markets. Table 1 shows an overview of the 19 specific markets and which category of market they belong. Rooftop and ground-mounted systems are considered the mainstream markets in the industry while BIPV and integrated products are considered niche markets. In the following section, I provide more details on the complementary assets needed in each market and on the criteria that customers use to evaluate technologies in each market.

Table 2-1 List of specific markets identified in solar PV and which macro category they belong to.

Specific sub-market	Market category
Residential rooftop systems	Rooftop systems
Commercial rooftop systems	
Ground-mounted systems	Ground-mounted systems
Solar tiles	Building-integrated photovoltaics
Building façade	
Solar glass	

Solar floor	
Off-grid	Integrated products
Canopy/shelters	
Military	
Consumer electronics	
Indoor applications	
Chargers	
Vehicles	
Aerospace	
Solar fabric	
Lights/lamps	
Sails	
Pumps	

2.2.1. Rooftop systems

Rooftop systems are among the first commercial applications developed in the solar PV industry. These systems are located on the roofs of residential and commercial buildings to generate electricity that will be used by that building.

As previously mentioned, many of the downstream complementary assets in the solar PV industry are market specific, i.e. different markets need different complementary assets.

For end users to enjoy their rooftop systems, the key market-related assets[1] are inverters (to transform electricity from direct current to alternate current), racking to install the solar panels on the roof and balance of system components such as wiring. Moreover, sales channels, distributors and specialized installers are needed. Given the high upfront cost of rooftop systems, often customers often need to obtain financing in the form of a bank loan.

[1] I use market-related and downstream complementary assets interchangeably to refer to those complementary assets necessary to bring the technology to market (e.g. for the user to enjoy a final product). Market-specific complementary assets are assets that are specific only to one market.

Customers in the rooftop system markets value efficiency, low costs and lifespan. In fact, the considerable upfront investment is more easily justified if the solar panels can produce the expected electricity for the expected number of years (the lifespan of a rooftop system is easily 20-25 years).

2.2.2. Ground-Mounted systems

Ground-mounted systems (often installed as solar farms or solar parks) are an application that is of interest to utilities and asset management firms. In fact, these large-scale systems are installed to feed the electricity back into the grid and to generate a profit.

The solar system itself shares some complementary assets with rooftops. More specifically, ground-mounted systems also need inverters, racking and balance-of-system components to function. Yet, other critical market-related assets that are specific to this market are engineering, procurement and construction firms (EPC firms) that develop these systems and often also operate them. The most typical financing for these systems is equity based thus requiring the involvement of equity firms.

Given the need to attract equity investors, there is a focus on generating high returns as fast as possible. For this reason, cost is the key performance attribute for ground-mounted systems followed by reliability to ensure a constant stream of energy and efficiency to maximize the amount of energy produced by one farm.

2.2.3. Building-integrated photovoltaics (BIPV)

The BIPV category includes several specific applications, such as solar tiles, solar glass and solar façades. The market-related assets necessary in BIPV differ significantly from those necessary for rooftops and ground-mounted systems. In fact, there is no need for racking, installers or EPC firms. The customers of BIPV markets differ from rooftop and ground-mounted systems and are often architectural and construction firms. Thus, the key sales channel needs to reach this different category of customers.

As BIPV is mostly used for green buildings, customers are less sensitive to cost or efficiency. On the contrary, they care about weight, flexibility and transparency as they play key roles in allowing design freedom and they determine the aesthetic of a building. Each specific market application, i.e. solar tiles, solar glass or solar façades, varies in which attributes it values. For example, customers of solar glass are most interested in transparency first. The solar façades market, however, is not particularly interested in transparency but rather cares about flexibility that allows design freedom.

2.2.4. Integrated products

The integrated products category includes those market applications in which solar cells are integrated into consumer products such as chargers, solar fabric or military applications (e.g. solar-powered military sensors). Given the need for tight integration into a product, some of the key complementary assets necessary in these markets are mini inverters, batteries and surge protection.

The markets included in this category evaluate technologies using criteria such as weight and flexibility because they facilitate integration. On the contrary, they are less concerned about efficiency. As in BIPV there are differences among the specific markets included in this category. For example, the market for solar fabric places the most value on flexibility while the market for aerospace is focused on weight as the lower the weight of a satellite, the less fuel is needed to launch it. Figure 3 shows a graphical representation of the downstream complementary assets needed in each of the four categories. Further information on the criteria used for evaluating technologies in the industry and in each market is provided in the Appendix (Table 1 and 2, respectively).

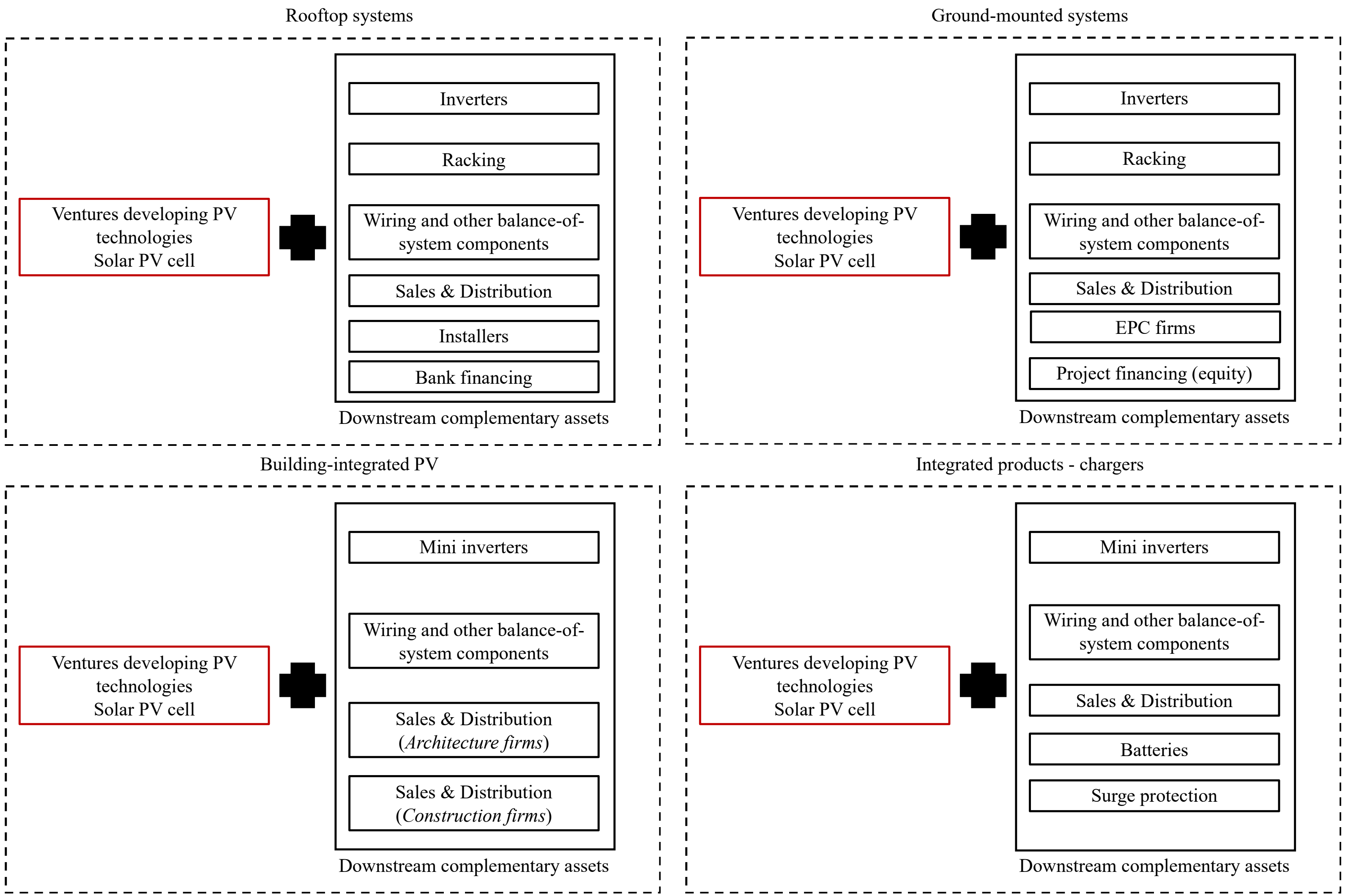


Figure 2-3 Overview of downstream complementary assets needed in each category of markets

2.2.5. Mainstream and niche markets

An interesting aspect of the solar PV industry is that markets can be categorized in mainstream and niche markets. Industry experts and participants alike agree on the existence of such mainstream and niche markets and categorize rooftop and ground-mounted systems as mainstream markets and BIPV and integrated products as niche markets. Not only are they considered mainstream and niche markets by industry participants, they also closely follow the definition given by the disruption literature (Christensen & Bower, 1996).

Following the literature on disruption (Christensen & Bower, 1996; Christensen, 1997), mainstream markets are established markets that present intense competition from established firms. These markets emerged with the old technology in the industry and, as such, co-evolved with this technology. Moreover, they present intense competition from incumbents of the old technology. In the solar PV industry, rooftop and ground-mounted systems map onto this definition. They both emerged thanks to and co-evolved with the first generation of solar technologies. Moreover, they are the markets presenting more intense competition because they are targeted by both firms developing silicon-based solar cells and thin film solar cells.

Niche markets emerged with the new technology because the new technology allowed products with new features or new products. Thus, niche markets serve underserved or new customers and present lower competitive pressure from incumbents of the old technology (Christensen & Bower, 1996). In the case of the solar PV industry, BIPV and integrated products are a great example of niche markets. They emerged with the second and third generation of the PV technologies which enabled new applications. Moreover, the intensity of competition is much lower because firms manufacturing silicon-based solar cells are less likely to target these markets. Thus, in niche markets, thin film technologies will be partially shielded from the competition with silicon and they have a market space in which they can improve in the hope to overtake silicon.

I extend the definition of mainstream and niche markets based on competition by also looking at the state of the value chain and of downstream complementary assets necessary to bring the technology to market. As the mainstream market co-evolved with the old technology, the value chain is well developed and the complementary assets within it are co-specialized to the old technology. In the solar PV industry, the value chain is well developed both upstream and downstream in the rooftop and ground-mounted markets. Upstream, the silicon technology can rely on knowledge from other industries. Downstream, complementary assets are well-developed and co-specialized to silicon, e.g. the racking systems were co-specialized to the thickness of silicon solar panels. Financing-wise, obtaining loans for systems using silicon-based cells was easier because silicon-based technologies could provide longer warranties. These characteristics made the competition for thin film in mainstream markets extremely difficult as they had to match silicon on efficiency and costs before moving the focus of the market to flexibility and weight.

The situation was quite different in niche markets as they had been enabled by thin film technologies. The value chain was not developed and therefore, the assets were not yet co-specialized to any technology. The limited development of the value chain meant that it was not clear how to integrate the solar cells into BIPV, for example, and the ventures needed to understand which sales channels to develop to reach the new set of customers of architectural and construction firms. This means that the ventures in these markets faced fewer challenges from the point of view of competition with silicon but intense challenges with respect to the development of value propositions and the associated value chain downstream. Table 2 shows a summary of the differences between mainstream and niche markets in the solar PV industry.

Table 2-2 Overview of differences in complementary assets between mainstream and niche markets

	Mainstream Market • Emerged with old technology • Within scope of incumbents	**Niche Market** • Emerged with new technologies • Outside scope of incumbents
Development of value chain	• Clear customer needs • Well-developed value chain *Upstream: Silicon-based technologies can be produced using standardized, off-the-shelf production machinery* *Downstream: To commercialize solar panels for rooftop systems, companies can rely on global distributors and, nationally, on large firms for installation. For rooftop and ground-mounted systems, there are national distributors such as SunRun and Vivint Solar in the US.* *Firms have long-term agreements with these distributors to reach installers.*	• Unclear customer needs • Not developed value chain *Upstream: Thin-film technologies require ventures to develop their own production processes. Solvoltaics developed AeroTaxi, a proprietary production process for PV nanowires. MidSummer developed its own machinery for the production of CIGS PV.* *Downstream: Firms cannot rely on the same distributors because of different customers. Onyx Solar Energy commercializes its PV glass to architects directly as there are not distributors in the solar PV industry at the moment specialized for BIPV.*
State of complementary assets	• Co-specialized to old technology *Mounting systems and wiring for rooftop systems follows industry standards. Racking systems for silicon-based solar panels is standardized.* *In rooftop systems, installers are used to installing rigid solar panels.*	• Unclear which complementary assets needed • Not co-specialized *Producers of thin-film panels need to work with producers of racking systems to develop systems that can support their panels. For example, to install thin-film solar panel in a large-scale ground-mounted system, Array Technologies (developer of racking systems) had to develop specific racking systems. The development of new racks was necessary to fit thinner panels compare to tradition silicon-based ones.* *In BIPV, companies cannot rely on established installers but need to address architectural firms or distributors of construction*

		material. At the time, there are no distributors for BIPV or consumer products.
Competition	• Incumbents' customer base • Intense competitive reaction *Large incumbents commercialize their technologies in the rooftop or ground-mounted markets. The top 10 companies in the solar PV industry (both modules and cell producers) are all targeting rooftop or ground-mounted systems.*	• Not included in incumbents' customer base • Less intense competitive reaction from incumbents *Of the top 10 thin film producers, only three pursue BIPV.*

3. PRODUCT MARKET CHOICES OF ENTREPRENEURIAL VENTURES: THE ROLE OF PRIOR EXPERIENCE

Abstract

The decision to enter a niche market is highly consequential for both the venture and the industry at large. In this paper, we show that prior technical, marketing-related and entrepreneurial experience shape the new ventures' propensity to pay attention to competition as well as to the challenges along the value chain and, in turn, affect the choice to enter a niche market. We further examine the propensity to choose niche markets when these types of prior experience have been accumulated in the same industry as the focal venture. Our findings show that the cognition of the venture team plays a key role in positioning to disrupt the industry. They also illuminate why ventures do not make decisions in line with the predictions of the disruption literature. In doing so, we begin to unpack why disruption rarely happens. Our empirical setting is the solar photovoltaic industry.

3.1. INTRODUCTION[2]

The theory of disruptive innovation has been around for 25 years and most MBA classes teach it in one form or another. Despite its prominence and popularity in the classroom, we see surprisingly few technology entrepreneurs making choices that align with this theory. Rather than targeting niche markets to gain a foothold into the industry and eventually disrupting its incumbents (Christensen, 1997; Christensen & Bower, 1996), entrepreneurs prefer to focus on criteria such as market size and immediate scalability to attract venture capital financing (Pahnke, Katila & Eisenhardt, 2015).

The institutional logics of different financial stakeholders that influence venture teams' strategic choices (Pahnke et al., 2015) are not the only factors that shape entrepreneurial cognition and behavior. Extant work on the cognitive origins of strategy underscores the importance of pre-entry experience to understand new venture choices (e.g. Boeker, 1988; Eisenhardt & Schoonhoven, 1990; Eggers & Song, 2015; Fern, Cardinal & O'Neill, 2012; Furr, 2019; Gruber, MacMillan, & Thompson, 2008, 2013). For instance, Fern et al. (2012) show the role of pre-entry experience of the founders and their teams on the choice of which geographic and product market to pursue and on the decision about the resources to use in their new venture. Prior experience of the venture team is also shown to affect the number and variety of potential market opportunities considered by the venture for its technology (Gruber et al., 2008; Gruber, MacMillan, & Thompson, 2012). Furr (2019) underscores the role of pre-entry experience on the venture's ability to adapt its products in response to changing conditions in the industry. Eggers & Song (2015) demonstrate that serial entrepreneurs are more likely to learn from their prior experience when they remain within the same industry. However, even though prior research establishes the key role played by pre-entry experience on ventures' strategic choices, we still know very little about how pre-entry experience

[2] This chapter was co-authored with Prof. Bart Clarysse and Dr. Anu Wadhwa

influences the choice technology entrepreneurs make to enter specific types of product markets within an industry.

In this paper, we address this gap by exploring the following question: *how does pre-entry experience of the venture team impact the decision of technology-based ventures to enter a niche product market?* The decision of which market(s) to pursue is highly consequential for ventures as well as for industries. The disruptive innovation literature has suggested that targeting niche product markets is an important element of a product market strategy and a key component of a disruptive strategy (Christensen & Bower, 1996; Christensen, 1997, Gans, 2016). Recent work highlights the role of experience in different user-industries on the decision to target multiple markets (Shermon & Moeen, 2020), providing initial evidence that prior experience plays a role on the decisions of which markets to tarket.

We draw on recent research that shows that industries can be segmented into different markets defined around specialized product clusters (Klepper & Thompson, 2006; Uzunca, 2018). We leverage this notion of segmented industries and conceptualize the differences between mainstream and niche product markets in terms of the availability and co-specialization of market-related complementary assets (Adner & Kapoor, 2010; Lawrence, 1999; Tripsas, 1997). In contrast to existing notions that commercialization challenges on the product market will be the same throughout the industry (Gans and Stern, 2003), we claim that these differences in niche and mainstream markets create distinct commercialization challenges in each type of market.

We argue that prior experience of venture teams in technical, marketing-related and entrepreneurial roles affects the mental models of the venture teams as well as their familiarity with challenges along the value chain, steering them towards challenges similar to those they are already accustomed to solving (Dane, 2010; Gavetti & Rivkin, 2007). Furthermore, we argue that acquiring experience in the same industry will alleviate some of the constraints imposed by pre-entry experience.

The empirical setting for this study is the solar photovoltaic (PV hereafter) industry. We collected detailed data on all the ventures that entered the solar PV industry to commercialize thin film technologies. Our data covers 117 ventures between 1985 and 2017. The solar PV industry is in an appropriate context for our research question for two reasons. First, thin film technologies were emerging technologies that brought about significant change and had the potential to disrupt the solar PV industry. These technologies relied on a significantly different knowledge base than existing silicon-based technologies and promised to change the basis of competition in the industry from a focus on energy efficiency to other features such as flexibility or transparency. Thus, they fit the definition of potentially disruptive technologies (Danneels, 2004, p.249). Second, solar PV technologies are generally commercialized in very different types of sub-markets. Of these sub-markets, rooftop and ground-mounted applications are widely considered to be mainstream markets by industry participants and experts, while building-integrated PV (BIPV hereafter) and integrated products represent niche product markets. Product markets like BIPV and integrated products are not only much smaller, but also have complementary assets of a very different nature compared to the rooftop and ground-mounted applications markets. Taken together, both technology and market points of view support the choice of the solar PV industry as an ideal context to study new ventures' entry choices related to niche and mainstream markets in an industry.

We find that entrepreneurial teams with primarily technical experience will be *less* likely to choose a niche market while teams whose members have more in-depth marketing experience and those with prior entrepreneurial experience will be *more* likely to choose a niche market. We also find an increase in the propensity to choose niche markets when technical and marketing-related experience have been acquired in the same industry as the focal venture. The findings in our study speak to different literatures. First, we show the importance of relevant industry, marketing-related and serial entrepreneurial experience as an antecedent of the choice of a disruptive strategy, whilst technical experience leads to mainstream market choices. Second, we add a cognitive element to the market entry literature, which has typically used an economic lens to predict how the analysis of downstream industries, given a strong appropriability regime, will determine the choice of entry (Gavetti & Rivkin, 2007; Gruber and MacMillan, 2017). Third, we extend the cognitive entrepreneurship literature, which has associated domain-specific experience with incremental improvements and rigidity, by showing that such domain-specific experience moderates the conservatism resulting from technical experience.

3.2. THEORY DEVELOPMENT AND HYPOTHESES

We base our definition of markets on recent work which has shown that industries may be segmented into different sub-markets (Klepper & Thompson, 2006; Uzunca, 2018). In light of our focus on the role of demand heterogeneity and market positioning, we use a definition of markets based on the products or services offered (Adner & Snow, 2010; de Figueiredo & Silverman, 2007). This definition is in line with prior work that defines markets as specialized product clusters that can be differentiated from others along dimensions such as the product or service offered, the customers targeted or the technology used (Klepper & Thompson, 2006; Uzunca, 2018).

This conceptualization allows us to distinguish between different markets within the same industry. In particular, consistent with the literature on disruptive innovation (Christensen & Bower, 1996), we characterize the markets that technology-based ventures developing a new and emerging technology may choose in order to enact their entry strategy into two types –

mainstream markets and niche markets. Entry into niche markets has been suggested as an important element of a product market strategy by the literature on demand-driven disruptive innovation (Christensen & Bower, 1996; Gans, 2016).

Mainstream markets are the established product markets that co-evolved with the old technology of the industry. As they emerged earlier and with the old technology, mainstream markets are product markets already served by the old technology and by incumbents commercializing that technology, forming the core of the incumbents customer base (Christensen & Bower, 1996).

Niche markets, on the contrary, are enabled by the new technology and emerge when the new technology allows to offer products with new features (Christensen & Bower, 1996) or competely new products (Gans, 2016). As they are enabled by the new technology, these markets are not served by firms that develop the old technology and are largely outside the scope of their customer base (Christensen & Bower, 1996). Thus, the key characteristics of niche markets lie in their emergence with the new technology and in being outside the competitive space of incumbents. These two characteristics lead to a number of differences between mainstream and niche product markets in terms of commercialization challenges. In the next paragraphs, we discuss these differences.

Because mainstream markets co-evolved with the old technology, they offer well-defined customer needs and well-developed value chains. In fact, incumbents responsible for developing the established technology have had time to understand which value proposition customers are looking for and to refine the old technology to satisfy customers. During this process of technology refinement, they have also had the time to understand which complementary assets are necessary to bring the technology to market and to develop them. Thus, incumbents responsible for developing the old technology are able to access important complementary assets that eventually position them advantageously vis-a-vis the new technology (Tripsas, 1997). Moreover, Incumbents developing established technology in mainstream markets have had time to influence standard setting and how complementary assets interact with the technology (Adner & Kapoor, 2010; Lawrence, 1999), leading to high co-specialization of complementary assets to the incumbents' offerings.

The state of the value chain and of complementary assets in niche product markets is very different. Given their recent emergence with the new technology, they offer undefined user needs. In fact, these new customers in the industry are still uncertain on the value proposition that they are looking for. Moreover, given the novelty of the market and the unclear value proposition, the value chain to bring the technology to market is largely absent. The ventures that enter niche markets to commercialize the new technology will need to invest considerable time and money to define the value proposition, identify the crucial complementary assets to bring the new technology to market in niche product markets and to build these market-related complementary assets. Thus, the value chain in niche product market is not as well defined as in mainstream markets and complementary assets also lack the co-specialization present in mainstream markets.

Finally, and keeping with the literature on disruptive innovation (Christensen & Bower, 1996), niche markets do not threaten the customer base of incumbents. Since mainstream incumbents pay little attention to ventures entering niche markets, the high competitive intensity predicted for successful commercialization on the product market (Gans & Stern, 2003) is prevalent in mainstream product markets, yet is much lower in niche product markets.

The above features of mainstream and niche markets mean that entrepreneurial ventures attempting technology commercialization will face different commercialization challenges in mainstream and niche product markets. Successful commercialization in the mainstream market will require satisfying well-defined user needs that has been widely influenced by the old technology. This is done by offering more refined technical solutions to existing problems.

As a consequence, the key challenges for ventures commercializing the new technology in mainstream markets involve intense technological competition with the old technology. This, in turn, involves resolving technical challenges in the upstream part of the value chain, such as issues of reliability, to develop the manufacturing process and bring it to scale in order to compete with the old technology. These technical challenges in the supply side need to be resolved under time pressure as mainstream markets are within the scope of incumbents of the old technology who can respond aggressively to entry of the new technology and squeeze the ventures out.

On the contrary, commercialization in niche markets will require developing a refined understanding of user needs and developing a new value proposition to attract them. At the same time, due to the newness and lack of value chain or specialized downstream complementary assets in the market, ventures will need to understand how to bring the technology to market, which assets are necessary and put them in place. This translates in intense commercialization challenges related to the demand-side and downstream part of the value chain. This is not to say that technical challenges in the upstream part of the value chain are absent in niche markets. Yet, they become less critical due to the lack of competitive pressure from the old technology. In fact, as niche markets emerged with the new technology, technical challenges do not suffer from the intense time pressure existing in mainstream markets allowing ventures critical time to resolve technical issues of reliability and scalability. Given these differences between niche and mainstream markets, factors that drive ventures to choose one or the other type of product market become crucial.

Research on entrepreneurship has long recognized that the entrepreneurial team’s prior experience affects new ventures’ choices as well as their outcomes (Beckman & Burton, 2008; Boeker, 1988; Eisenhardt & Schoonhoven, 1990). The breadth of pre-founding experience allows for more flexibility for ventures to adapt to changing circumstances whereas the depth of experience restricts such ability to adapt (Furr, 2019). Prior experience in different roles has also been found to affect the processes of technology-market linking (Gruber et al., 2008; 2012). Venture teams with prior managerial or entrepreneurial experience possess a generalist view that helps them consider more potential applications for their technologies, while prior specialist experience in technical and marketing roles limits their ability to generate large opportunity sets (Gruber et al., 2008, 2012). Similarly, it has been suggested that prior entrepreneurial experience translates into clearer and more richly defined mental prototypes about business opportunities which are more focused on actually starting and running the business and prioritize customer orientation over technical novelty (Baron & Ensley, 2006). In a similar vein, prior experience in a specific function influences the knowledge structures and cognitive frames of individuals (Fern et al., 2012). Such individuals develop ingrained assumptions about the environment and activities associated with their roles and, for this reason, are likely to filter out alternatives (Ward, 2004). Overall, this literature points out that prior experience of the entrepreneurial team affects the strategic decisions of entrepreneurial ventures. Thus, this is likely to also affect the decision to choose a mainstream or niche product market. However, we still know little about this relationship. In this paper, we respond to this gap and ask the question, *how does pre-entry experience of the venture team impact the decision of technology-based ventures to enter a niche product market?*

The decision of which product market to enter requires careful consideration of the environment and challenges that an entrepreneurial venture is likely to face in the chosen market (Adams, Fontana, & Malerba, 2016; Shermon & Moeen, 2020). Environments that are ambiguous and difficult to analyze, such as emerging industries characterized by extreme uncertainty on multiple aspects related to technology and demand, generate intense cognitive demands and may compel individuals to solve problems by relying on their prior experience. From a cognitive perspective, such intense cognitive demands render them more likely to see cues aligned with their expertise and to interpret stimuli according to their previously learned frames (Hambrick, Finkelstein, & Mooney, 2005). Moreover, intense cognitive demands make them more likely to rely on mental frames that let them leverage their existing knowledge and skills. In this paper, we examine the role of three types of experience – technical, marketing-related and entrepreneurial - on the choice to enter niche product markets. Collectively, these three types of experiences have been shown to theoretically and empirically impact the cognitive maps of founders (Gruber et al., 2008;2012; Furr, Cavaretta & Garg, 2012; Furr, 2019). Additionally, we also examine whether acquiring prior experience in the same industry impacts these relationships. Since the uncertainty surrounding emerging industries makes individuals even more likely to use case-based search and analogical thinking, venture teams with prior experience in the same industry may be quite knowledgeable about the segment-specific dynamics of the industry and may have developed a unique understanding of the role played by complementary assets and value chains.

3.2.1. Prior experience in technical roles

Prior experience in technical roles, such as chief scientist, chief technologist or head of engineering, helps individuals develop mental frames that influence how they interpret organizational problems (Finkelstein, Hambrick, & Cannella, 2009). Such individuals construe technology development in terms of technical problem-solving and characterize technological competition in terms of which technology can best solve a problem (Dunbar & Fugelsang, 2005). Thus, they prefer well-defined consumer problems that they can solve more efficiently.

The mindset developed by individuals during prior employment in technical roles influences to what they will pay attention (Ocasio, 1997). When faced with a current problem of identifying a suitable product market in which to commercialize their technology, these individuals will apply lessons from their past experience (Gilboa & Schmeidler, 2001). Individuals with prior technical experience are more likely to be familiar with the spectrum of competing technologies and are motivated to develop superior solutions that would help them win the technological race. Prior experience in a role typically entrenches people in a trajectory and it makes it easier for individuals to apply what they have learnt in the past to their new endeavors (Dane, 2010; Gavetti & Rivkin, 2007). Individuals with prior experience in technical roles not only will be more familiar with competing technologies and with technological races but they will also have the necessary knowledge to engage in actions that help solving hard technical problems.

Niche markets lack characteristics with which individuals with prior technical experience are familiar. Such markets do not witness intense technology-based competition and user needs are not well defined. Therefore, ventures whose team members have prior technological experience and who favor markets with well-defined problems to develop more advanced solutions are far more likely to be attracted to mainstream markets which present them with fundamental technological challenges upstream in the value chain. In such markets, the technology is relatively mature and further along its technological trajectory, thus, firms strive to develop and commercialize more refined technical solutions for well-known customer needs. Technically experienced venture teams entering with the new technology will favor mainstream markets because they see an opportunity to user their technology to resolve technical and manufacturing-related problems with which they are familiar because of their cognitive frames. Moreover, technically experienced teams also possess the necessary skills to work on these problems, making mainstream markets a particularly attractive choice where to use their knowledge and skills to move along the technology trajectory quickly and to compete with the old technology. Therefore, we hypothesize that,

Hypothesis 1 (H1). *The greater the technical experience of entrepreneurial venture teams, the less likely they are to enter niche product markets.*

3.2.2. Prior experience in marketing-related roles

Prior experience in marketing-related roles leads to development of mental frames that influence how individuals interpret organizational problems related to potential customers. Individuals with prior experience in roles such has chief marketing officer or vice president (VP) of sales have detailed, deep experience with products and user applications that leads them to characterize technology development in terms of end-user application. They are adept at identifying and assessing new markets, researching competition, and developing or accessing market-related complementary assets such as sales and distribution (Danneels, 2008).

Prior marketing-related experience influences the types of challenges venture teams will be drawn to and the type of markets they will choose. Framing technology development in terms of end-user application creates a predisposition to rely more upon past experience and competence when solving customer-centric problems. Teams with prior experience in marketing-related roles are more likely to pay attention to market-specific problems (Ocasio, 1997). They may focus on addressing challenges related to downstream complementary assets, such as creating, developing and accessing market-related resources, rather than technical challenges encountered upstream in the value chain.

Niche markets are attractive markets for venture teams with prior experience in marketing-related roles because certain characteristics of these markets - considerable ambiguity and uncertainty surrounding customer needs, market structure, product features, the degree to which complementary assets are available, and uncertainty about how to reach potential customers in the most effective way - bring to the forefront commercialization challenges typically encountered downstream in the value chain.

Prior experience in marketing-related roles also equips venture teams with critical knowledge and skills that can help them resolve downstream commercialization challenges. In fact, through their prior experience in marketing-related roles, teams have developed wellhoned skills at identifying new customers and building relationships with them. Moreover, they have knowledge of how to build the resources, i.e. complementary assets, necessary to reach new customers (Danneels, 2008).

Thus, from a cognitive perspective, teams with prior marketing-related experience will be attracted to niche markets because these markets fit their existing mental frames. Moreover, from a knowledge perspective, their skills on how to identify markets and serve customers in those markets (Dane, 2010) make them particularly well place to enter niche markets. Thus, we hypothesize that,

Hypothesis 2 (H2). *The greater the marketing-related experience of entrepreneurial venture teams, the more likely they are to enter niche product markets.*

3.2.3. Prior experience in entrepreneurial roles

Research on serial entrepreneurs shows that prior experience in entrepreneurial roles helps individuals acquire knowledge and develop heuristics that will help them in their next venture (Eggers & Song, 2015). Because of their prior entrepreneurial experience, serial entrepreneurs develop simple rules about opportunity selection that help them to decide which market to pursue (Bingham & Eisenhardt, 2011).

Serial entrepreneurs are equipped with mental prototypes that facilitate opportunity identification (Baron & Ensley, 2006). Experienced entrepreneurs focus, much more than novice entrepreneurs, on a wider array of factors pivotal to successfully starting and running a venture, such as managing risk, meeting customer needs or generating cashflows, rather than on peripheral aspects, such as the novelty and uniqueness of the technology in itself (Baron & Ensley, 2006). Thus, experienced entrepreneurs prefer markets where they can more easily manage the risk associated with scaling up their venture and markets with unsolved user needs (Baron & Ensley, 2006; Bingham & Eisenhardt, 2011). Their prior entrepreneurial experience also means that these individuals have developed knowledge of how to identify such high-potential opportunities and useful skills about how to best serve these markets and claim them (Baron & Ensley, 2006: Santos & Eisenhardt, 2009).

Opportunities available in niche markets possess attributes that find a good match with the mental frameworks of individuals with prior entrepreneurial experience. As we have argued, niche product markets do not suffer from intense technological races and are characterized by unclear customer needs and value propositions (Santos & Eisenhardt, 2009). The absence of incumbents or incumbents' attention in such markets eases the time pressure on entrepreneurial ventures who do not need to prove technological superiority or scale up quickly to win a technological race. Overall, niche product markets represent spaces that fit the preferences of experienced entrepreneurs who evaluate and choose promising opportunities based on manageable risk rather than on the uniqueness and superiority of the technology (Baron & Ensley, 2006). Moreover, these markets also fit the existing skills of experience entrepreneurs who, through their experience, have developed knowledge of how to claim markets and establish an irrevocable presence (Santos & Eisenhardt, 2009). Taken together, these two arguments – fit with mental frameworks and skills to succeed – suggest that venture teams whose members have prior entrepreneurial experience will be more likely to choose niche product markets, compared to teams without such prior experience.

Hypothesis 3 (H3). *The greater the entrepreneurial experience of entrepreneurial venture teams, the more likely they are to enter niche product markets.*

3.2.4. The role of gaining prior experience in the focal industry

So far, we have discussed the effect of different types of prior experience on the decision to enter a niche product market. However, entrepreneurs and venture team members may have acquired their experience in a multitude of industries before entering the current industry (Furr et al., 2012). When venture team members have prior experience in an industry that they aspire to re-enter with subsequent ventures, their accumulated knowledge about the specific, commonplace processes in the industry equips them with a broader view and an improved understanding of the industry (Agarwal & Shah, 2014; Furr et al., 2012). We focus on how different types of experience – technical, marketing-related and entrepreneurial - and prior experience in the focal industry jointly affect product market choice.

In hypothesis 1, we posited that venture teams who have prior technological experience will be less likely to choose niche product markets due to their preference for solving technological challenges upstream in the value chain that do not match the commercialization challenges found in niche product markets and due to their knowledge of how to best solve challenges found in mainstream markets.

When venture team members' technical expertise has been acquired in the same industry that they are looking to re-enter, the venture team has experience in developing technologies specifically for the focal industry, giving them first-hand knowledge of customers' expectations in the industry. Compared to teams with only technical experience, these teams have a more holistic understanding of dynamics both upstream and downstream in the value chain of the industry. This holistic understanding will diminish their reliance on cognitive frames focusing on upstream technical challenges. Moreover, teams with both technical and industry experience have knowledge that helps them recognize whether and how their technology might address different product markets. These two arguments, taken together, suggests that, venture teams that gained prior technological experience in the focal industry are less likely to rely exclusively on their preference for solving upstream technical challenges and have knowledge of how to address different product markets that make them more likely to choose niche markets, compared to teams with exclusively technical experience.

In hypothesis 2, we argued that venture teams with prior marketing-related experience are drawn to niche product markets because niche markets present the downstream commercialization challenges that venture teams with this type of prior experience favor and have the necessary skills to solve (Danneels, 2008). Having already commercialized products in the industry, team members with prior experience in the focal industry possess deep contextual knowledge of the customers and state of product markets in the industry (Agarwal, Echambadi, Franco, & Sarkar, 2004). The effect of this contextual experience is twofold. First, it makes it even easier for teams with prior marketing-related experience to identify markets presenting the challenges they favor. Second, the customer competences they have developed are specialized to the industry and makes it easier to solve the downstream commercialization Additionally, their knowledge of incumbents' and the customer segments served by incumbents allows them to circumvent or sidestep those markets where new entrants might face potentially intense competitive responses (Christensen & Bower, 1996). Thus, ventures whose team members have gained their prior marketing-related experience in the focal industry will be even more likely to choose niche product markets than teams that earned that type of experience in a different industry.

We argued in hypothesis 3 that prior entrepreneurial experience leads ventures to choose niche markets because these markets possess features that experienced entrepreneurs favor when examining potential opportunities. Moreover, they possess the capabilities necessary to identify high-potential opportunities and to claim these spaces. The deep contextual knowledge deriving from prior experience in the same industry makes it easier for ventures to scan the industry environment and identify high-potential opportunities compared to venture teams that gained experience in other industries. Thus, venture teams with both entrepreneurial and focal industry experience have an advantage in recognizing spaces that offer the opportunity features favored by experienced entrepreneurs. As their preference for niche markets and knowledge of how to claim high-potential spaces coming from their professional expertise is combined with superior knowledge of the industry making it easier to scan the environment for such spaces, venture teams with both prior entrepreneurial and focal industry experience have an even greater propensity to choose niche product markets than venture teams with only prior entrepreneurial experience.

Taking together the aforementioned arguments, we present the following hypotheses.

Hypothesis 4a (H4a). *Entrepreneurial venture teams with greater prior technical and focal industry experience are more likely to choose niche product markets than teams with no focal industry experience.*

Hypothesis 4b (H4b). *Entrepreneurial venture teams with greater prior marketing-related and focal industry experience are more likely to choose niche product markets than teams with no focal industry experience.*

Hypothesis 4c (H4c). *Entrepreneurial venture teams with greater prior entrepreneurial and focal industry experience are more likely to choose niche product markets than teams with no focal industry experience.*

3.3. DATA AND METHODS

3.3.1. Empirical Context

We test our hypotheses in the context of the global solar PV industry from the time of first entry of a venture developing thin film technologies (1985) to 2017. We focus on ventures developing solar technologies – technologies that transform solar energy into electricity – which are positioned midstream in the value chain of the industry according to the literature on innovation ecosystems (Adner & Kapoor, 2010, 2016). Thus, we exclude ventures developing technologies used to produce upstream components or downstream complements. This categorization is consistent with prior research on this industry (Furr & Kapoor, 2018; Hannah & Eisenhardt, 2018; Kapoor & Furr, 2015).

The solar PV industry is an appropriate context to explore our research question and test our hypotheses for several reasons. First, the industry is characterized by several technological generations that compete against each other. The technology that gave rise to the solar PV industry was silicon-based. Thin film technologies – the new technologies - have brought about technological change in the industry in two ways. From the perspective of the production process, they rely on deposition of semiconductor materials on a thin plastic film rather than relying on slicing a silicon ingot. As they rely on a different knowledge base than the traditional silicon-based technology, it was necessary to resolve technological issues of efficiency, reliability and production process development. From the perspective of technology evaluation, thin film technologies held great promise regarding cost-efficiency performance (Osborne & Hinckley, 2007), as illustrated by the following quote: "*thin film technologies will offer the lowest cost per watt at the module level for the foreseeable future, with cadmium telluride (CdTe), a disruptive technology at the module level, presently less than half the cost per watt of crystalline silicon (c-Si) approaches*." (O'Rourke, Kim, & Polavarapu, 2007). Furthermore, these technologies promised to change the basis of competition from efficiency to flexibility, weight and transparency. Thus, following Danneel's definition (2004, p.249), they qualify as potentially disruptive technologies which makes them a particularly suitable context for our study.

Furthermore, solar PV technologies can be commercialized in different markets. During the data collection, we identified 19 product markets around specific applications[3]. These 19 markets range from traditional rooftop systems, ground-mounted systems for solar farms to more novel applications such as solar glass or solar fabric. These 19 markets can be further

[3] The complete list of markets is provided in Chapter 2.

categorized in four different categories of market: rooftop systems, ground-mounted systems, building-integrated PV (BIPV) and integrated products (e.g. chargers). Rooftop systems and ground-mounted systems share some similarities in that the structure of the system surrounding the solar panels is largely the same, with size of the system and amount of electricity produced being the main differentiator. BIPV and integrated products are fundamentally different than rooftop and ground-mounted systems but rely on similar knowledge about how to integrate the technology into a product.

In the solar PV industry, rooftop applications and ground-mounted systems are the mainstream markets while BIPV and integrated products are considered niche markets by analysts and industry experts (KnowledgeTransferNetwork, 2013; SolarServer, 2010). A report from the National Renewable Energy Laboratory (NREL) in 2010 defined residential rooftop installations as the dominant application in the solar PV industry (Ardani & Margolis, 2010). The following quote illustrates this point for BIPV, "*Because BIPV has been known mostly for showcasing solar applications in sustainable building designs, it has been regarded as a niche product compared to rack-mounted PV products*" (James, Goodrich, Woodhouse, Margolis, & Ong, 2011). At the same time, a recent article states that "*The new [NREL] study of rapidly evolving prospects for solar energy suggests there are possibilities for "niche markets" reaching volumes of $1 billion over the next decade.*" The article goes on to describe a number of applications that are considered niche markets, such as "*lightweight and more compact solar power in small space satellites*" and consumer goods such as "*indoor light harvesting or generating power from a mix of interior lighting"* (Fialka, 2018). Of the ventures in our sample, 40% chose niche product markets. While the present study covers several decades of the industry PV industry, the state of the markets in the industry largely remained the same, i.e. markets that were niches in the early 2000s, such as solar glass, are still niche markets 20 years later.

The product markets in the solar PV industry reflect the conceptual distinction between mainstream vs. niche markets discussed above. Ventures that chose to commercialize their thin film technology in rooftop or ground-mounted systems had to quickly prove efficiency and scalability in order to compete with the older silicon-based technologies that had high efficiency and could be mass produced. Furthermore, thin film technologies that entered the mainstream markets had to also prove they did not deteriorate over time to compete with the 25-year warranty offered by silicon-based producers. The need to prove efficiency, scalability and low deterioration led to intense technological challenges to resolve technical issues. On the contrary, ventures that chose niche markets such as BIPV had to develop the entire ecosystem of downstream complementary assets. For example, they had to partner with new types of companies such as architecture or construction firms to integrate their technologies in construction materials and designs of new buildings. Table 1 (already presented also in Chapter 2) provides examples from the solar PV industry that illustrates how the theoretical difference between mainstream and niche markets discussed in the background section maps onto the empirical context.

Table 3-1 Overview of differences in complementary assets between mainstream and niche markets

	Mainstream Market • Emerged with old technology • Within scope of incumbents	**Niche Market** • Emerged with new technologies • Outside scope of incumbents
Development of value chain	• Clear customer needs • Well-developed value chain *Upstream: Silicon-based technologies can be produced using standardized, off-the-shelf production machinery* *Downstream: To commercialize solar panels for rooftop systems, companies can rely on global*	• Unclear customer needs • Not developed value chain *Upstream: Thin-film technologies require ventures to develop their own production processes. Solvoltaics developed AeroTaxi, a proprietary production process for PV nanowires. MidSummer developed its own machinery for the production of CIGS PV.*

	distributors and, nationally, on large firms for installation. For rooftop and ground-mounted systems, there are national distributors such as SunRun and Vivint Solar in the US. *Firms have long-term agreements with these distributors to reach installers.*	*Downstream: Firms cannot rely on the same distributors because of different customers. Onyx Solar Energy commercializes its PV glass to architects directly as there are not distributors in the solar PV industry at the moment specialized for BIPV.*
State of complementary assets	• Co-specialized to old technology *Mounting systems and wiring for rooftop systems follows industry standards. Racking systems for silicon-based solar panels is standardized.* *In rooftop systems, installers are used to installing rigid solar panels.*	• Unclear which complementary assets needed • Not co-specialized *Producers of thin-film panels need to work with producers of racking systems to develop systems that can support their panels. For example, to install thin-film solar panel in a large-scale ground-mounted system, Array Technologies (developer of racking systems) had to develop specific racking systems. The development of new racks was necessary to fit thinner panels compare to tradition silicon-based ones.* *In BIPV, companies cannot rely on established installers but need to address architectural firms or distributors of construction material. At the time, there are no distributors for BIPV or consumer products.*
Competition	• Incumbents' customer base • Intense competitive reaction *Large incumbents commercialize their technologies in the rooftop or ground-mounted markets. The top 10 companies in the solar PV industry (both modules and cell producers) are all targeting rooftop or ground-mounted systems.*	• Not included in incumbents' customer base • Less intense competitive reaction from incumbents *Of the top 10 thin film producers, only three pursue BIPV.*

3.3.2. Data collection and data sources

This study involved an extensive data collection effort. In the first phase, in order to familiarize ourselves with the industry and its dynamics, we conducted semi-structured interviews with industry participants and one of the authors read reports covering the industry between 2003 and 2016. In the second phase, to collect the quantitative data for analysis, we first identified all the entrepreneurial ventures that entered the solar PV industry to commercialize thin film technologies. We obtained a list of all industry entrants from i3 – a consultancy specialized in clean technology sectors - and triangulated the list using industry reports. This process enabled us to identify four ventures that were active in the solar PV industry but not included in the list obtained by i3. Our final sample consists of 117 ventures that entered the industry with thin film technologies.

Next, we coded data on the market entry strategies pursued by the ventures from press releases and from specialized media outlets (e.g. Photon Magazine). This data collection method has been used in previous industry studies (de Figueiredo & Silverman, 2007; Marx, Gans, & Hsu, 2014). The solar photovoltaic industry received extensive attention in the media because of the substantial public interest in climate change as well as the large investments made by governments in these technologies. This enabled us to code market strategies and collect further information on the ventures such as the size of their production facilities, the technology development stage, and customer and partnership announcements. This was complemented with information on the financing rounds of these ventures from i3 and VentureXpert. This data was augmented with technology-level and industry-level data obtained from academic publications (e.g. Progress in Photovoltaics) and NREL publications.

In the final phase, we compiled detailed information on the background of every member of each venture team. In the solar PV industry, venture teams included typically include individuals beyond the founders due the technically intensive nature of the industry that requires individuals with different knowledge backgrounds. Thus, the data on the venture team includes founders and individuals that were part of the executive team of the ventures such as individuals in the C-level (e.g. Chief Technical Officer, Chief Scientific Officer or Chief Financial Officer) and at the VP level (e.g. Vice President of Sales or Vice President of Semiconductor Material). We identified these individuals by compiling detailed company histories and prior experience was coded from their employment histories (Beckman, Burton, & O'Reilly, 2007) which we obtained from company websites, LinkedIn, Bloomberg and CVs.

3.3.3. Measures

Dependent variable

Our hypotheses predict the likelihood of choosing a niche product market. We focus on the first market targeted by the venture. The dependent variable, *niche market*, is a binary variable which is equal to 1 if the venture first entered a niche product market and 0 if the venture entered a mainstream product market. We compiled a list of all market applications and then coded each market as either mainstream or niche. Following evidence from our qualitative work, we coded BIPV and integrated products such as solar chargers or solar lights as niche product markets.

Independent variables

We use three variables to measure different types of functional experience in venture teams. *Prior technical experience* is measured as the percentage of team members having prior experience in technical roles such as Chief Technology Officer, Chief Scientist or engineering lead. This coding is in line with extant work examining prior experience in teams (Almandoz, 2012, 2014; Furr, 2019). *Prior marketing-related experience* is measured as the percentage of team members having prior experience in customer-related roles such as Chief Marketing Officer and VP of Sales. We operationalize *prior entrepreneurial experience* as the percentage of team members who had been entrepreneurs before joining the focal venture. These three measures of functional experience include experience in any industry, not only in the focal one. *Prior experience in the focal industry* measures the percentage of team members that have accumulated experience in the solar PV industry before joining the venture. This measure ignores the type of function that was covered by each team member and focuses on the industry in which the experience was accumulated.

For example, the venture team of Heliovolt in 2005 included 3 individuals: the founder, the VP of business development and the VP of marketing. The founder had previous technical, marketing-related experience and solar industry experience. The VP of business development had previous technical experience. The VP of marketing had previous technical and marketing-related experience. To calculate the variable *Prior technical experience*, we sum the number of members with technical experience (3 in this case) and then divide by the total number of members (3 in this case). Thus, for Heliovolt in 2005 *Prior technical experience* equals *1.* The other variables are calculated in a similar way. *Prior marketing-related experience* equals 0.667 from 2 members having this type of experience over 3 total members. *Prior entrepreneurial experience* equals 0 as no member had this type of experience. Finally, *prior experience in the focal industry* equals 0.334, from 1 of 3 members having this type of experience.

Nanosolar in 2002 had two members in the venture team: the CEO/Founder and President/Founder. The CEO had previously earned technical and entrepreneurial experience. The president had earned marketing-related experience before joining the venture. None of them had prior experience in the solar PV industry. Thus, *Prior technical experience* equals 0.5 as one of two members had this type of experience. Similarly, *Prior marketing-related experience and Prior entrepreneurial experience* both equal 0.5 as only one of two team members had marketing-related and entrepreneurial experience respectively. Finally, the variable *prior experience in the focal industry* is equal to 0 as none had experience in the solar PV industry.

Control variables

We control for several factors that can influence the choice of market. At the firm level, we control for whether the venture is also producing any of the downstream complementary assets, to control for access to complementary assets necessary for commercialization (Qian, Agarwal & Hoetker, 2012). We also control for the possibility that a venture has raised financing before deciding which market to target. We include two variables that measure the amount of financing raised through venture capital and government-sponsored financing, respectively. *VC financing* and *government-sponsored financing* influence how firms innovate (Pahnke et al., 2015) and may also influence the choice of product market. We also control for the *development stage* of the technology being developed by the venture - this is an ordinal variable which equals 1 when the venture is still in the technology development phase, equals 2 when the venture has reached the pilot phase and equals 3 when the venture has reached wide commercial availability (Kazanjian, 1988). Moreover, we control for *company size* using the size in megawatts (MW) of the installed capacity (Furr & Kapoor, 2018), a commonly used measure in the industry to measure size of firms. Finally, we control for the *number of patents* applied for by the venture (Gambardella & Giarratana, 2006).

At the industry level, we control for the *size of niche markets* measured in cumulative megawatts (Furr & Kapoor, 2018). This is to control for the effect that as niche markets grow, they may become more attractive options for entrants. We also control for the *cumulative production of thin film technologies* (in MW) to control for learning curve effects at the technology level (Kapoor & Furr, 2015). Finally, we control for competition in niche markets by including the number of firms competing in niche market in the year and its quadratic term (*no. niche companies* and *no. niche companies^2*) (Hannan & Freeman, 1977). Finally, we include *year* dummies to control for differences in founding conditions (Agarwal et al., 2004).

3.3.4. Analytical method

We test our hypotheses using a semiparametric Cox proportional-hazard regression model as it does not make assumptions about the distribution of the baseline hazard function (Cox, 1972; Cox, 2018). This method is appropriate because we have an unbalanced panel dataset that covers each venture from the year in which in entered the industry to the year in which it announced the first market they were targeting. Using the announcement of the market is appropriate in the solar PV industry because ventures either announced the market at the same time in which they unveiled a prototype or full product for that specific markets or, when announcing the target markets when still in the technology development phase, they typically followed through and actually entered that market in the same year or the following years.

Furthermore, this method allows us to include time-varying measures in our analysis. This is necessary because in the solar PV industry the venture teams often changed over time.

3.4. EMPIRICAL RESULTS

Table 2 presents descriptive statistics and pairwise correlations among our variables. Though most of the correlations between the independent variables are low to moderate, we checked for multicollinearity before proceeding with the analysis. We calculated variance inflation factors (VIF) based on the full model. Average VIF was 5.83 with each value below the value of concern of 10 (Neter, Kutner, Nachtsheim, & Wasserman, 1996; O'brien, 2007).

Table 3-2 Pairwise correlation and summary statistics

		Mean	SD	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Niche Market	0.17	0.37	0	1	1															
2	Prior Technical Experience	0.76	0.31	0	1	-0.02	1														
3	Prior Marketing-Related Experience	0.16	0.28	0	1	0.03	0.13	1													
4	Prior Entrepreneurial Experience	0.53	0.42	0	1	-0.04	0.09	0.14	1												
5	Prior Solar-PV-industry Experience	0.55	0.44	0	1	-0.01	0.21	0.20	0.61	1											
6	Vertically Integrated	0.16	0.37	0	1	-0.01	-0.21	0.01	-0.10	-0.12	1										
7	Gov. Financing	0.04	0.39	0	4.9	0.03	-0.12	-0.06	0.01	0.05	0.08	1									
8	VC Financing	4.93	30.05	0	366.1	-0.06	-0.05	0.06	0.02	0.06	-0.06	0.03	1								
9	Tech. Dev. Stage	1.16	0.41	1	3	-0.06	-0.14	0.01	0.04	0.14	0.10	0.07	0.37	1							
10	Company Size	0.21	0.78	0	4.71	-0.07	-0.12	0.06	0.05	0.09	0.03	0.04	0.56	0.73	1						
11	No. of Patents	0.04	0.21	0	2	0.02	-0.10	0.02	-0.10	0.07	-0.03	0.20	0.11	0.19	0.24	1					
12	Size of Niche (cum MW)	1734.01	3239.67	0	31327	0.03	0.15	0.00	0.05	0.14	-0.14	0.00	-0.04	0.07	-0.06	-0.04	1				
13	Cum. Prod. of TF Tech	4414.85	6587.45	12.69	42128	0.05	0.16	0.01	0.07	0.16	-0.16	0.01	-0.06	0.06	-0.07	-0.05	0.94	1			
14	No. Niche companies	46.71	31.75	0	109	0.08	0.13	0.00	0.11	0.15	-0.22	0.07	0.00	0.06	-0.02	-0.01	0.69	0.84	1		
15	No. Niche companies^2	3186.79	3408.40	0	11881	0.07	0.14	0.01	0.09	0.17	-0.20	0.05	-0.04	0.06	-0.04	-0.03	0.78	0.94	0.96	1	
16	Years	2006.11	5.33	1985	2017	0.08	0.12	0.01	0.07	0.07	-0.20	0.06	0.04	0.04	0.00	0.01	0.55	0.63	0.86	0.74	1

n=276

Table 3 reports the results from the Cox proportional-hazard model that tests the Hypotheses. Model 1 presents the baseline model with only control variables. Model 2 to Model 4 introduces the variables prior technical experience, prior marketing-related experience and prior entrepreneurial experience to test Hypotheses 1 to 3, respectively. Model 5 to Model 8 introduce the interaction terms to test Hypothesis 4. Finally, Model 8 presents the full model. Results are reported as hazard ratios – a coefficient higher than 1 is associated with a positive effect, while a coefficient lower than 1 is associated with a negative effect.

Results from the baseline model (Model 1) suggest that raising VC financing has a negative effect on the decision to enter a niche market (β=0.98, p-value=0.032). The number of patents that a venture has applied for also has a positive and significant effect on the decision to enter a niche product market (β=2.018, p-value=0.000). As expected, as the total installed capacity in niche markets increases, ventures are more likely to enter such niches (β=1.014, p-value=0.000). This supports the idea that as the market grows, it becomes more attractive for new entrants. At the same time, the higher the production of thin film technologies at the industry level, the less likely ventures developing them are to commercialize them in niche markets (β=0.984, p-value=0.000).

Hypothesis 1 predicts that ventures whose team members have prior experience in technical functions will be less likely to choose niche markets. We find that the effect of prior technical experience on choice of niche is negative (β=0.780, p-value=0.000), supporting Hypothesis 1.

In Hypothesis 2, we predicted that venture teams which have members with prior experience in marketing-related functional roles such as chief marketing officers or VP of Sales are more likely to choose niche product markets because they are more familiar with how to develop customer competences. Model 3 shows that the coefficient related to the variable, prior marketing-related experience, is positive (β=1.518, p-value=0.037) and provides support for our Hypothesis 2.

In Hypothesis 3 we argued for a positive effect of prior entrepreneurial experience on the choice of a niche market. The coefficient associated with prior entrepreneurial experience is positive in Model 4 (β=1.212, p-value=0.013), thus, supporting Hypothesis 3.

To give a sense of the size of the effect, we use the technique advocated by Zelner (2009) to model the predicted probabilities for different levels of the different types of prior experience. A venture with no prior technical experience (and other types of experience at means) has a predicted probability of choosing niche markets of 19.52%. For a venture with mean levels of prior technical experience, this predicted probability decreases to 16.78%. Similarly, a venture with no prior marketing-related experience (other types of prior experiences at means) has a predicted probability of choosing niche markets of 15.81%. When prior marketing-related experience is at the mean, this probability becomes 16.78%. The probability raises to 23.05% when all members of the team have this type of experience. Finally, a venture with no prior entrepreneurial experience (other types of prior experiences at means) has a predicted probability of choosing niche markets of 15.62%. This probability raises to 16.78% and 17.89% when a venture has mean prior entrepreneurial experience or every member of the team has this type of prior experience, respectively.

Finally, Hypothesis 4a-c looks at the moderating effect of prior experience in the focal industry on the relationship between prior experience in a role and the choice of niche market. We predicted a positive moderating effect of gaining prior experience in the focal industry on the relationships predicted in Hypotheses 1 to 3. In Model 5, we find that the coefficient associated with the interaction between prior technological experience is positive (β=7.284, p-value=0.000), supporting H4a. Model 6 shows the interaction between prior marketing-related experience and prior focal experience. The sign of the interaction is positive (β=8.173, p-value=0.000), thus supporting H4b. In Model 7, we find that the sign associated with the interaction term between prior entrepreneurial experience and focal industry experience is negative (β=0.571, p-value=0.000), offering no support for H4c.

To further examine the effect of gaining experience in the focal industry on the relationship between the types of prior experience examined in the first three hypotheses and the choice of niche market, we graphed the interaction effects of Model 5 (Figure 1), Model 6 (Figure 2) and Model 7 (Figure 3) using the technique advocated by Zelner (2009). The y-axes of the graphs show the predicted likelihood of choosing niche markets. The different curves represent different levels of prior experience in the focal industry. Figure 1 depicts the interaction between prior technical experience and focal industry experience. We see that the negative effect of prior technological experience is weakened when venture teams have increasing levels of experience in the focal industry in line with H4a. Figure 2 shows the interaction effect between prior marketing-related experience and focal industry experience. The graph shows that for increasing levels of prior experience in the focal industry above the mean, the positive relationship between prior marketing-related and the likelihood of choosing niche markets becomes stronger. Thus, Figure 2 suggests support for H4b. Finally, Figure 3 shows the interaction effect of prior entrepreneurial experience and prior focal industry experience. Contrary to the prediction of H4c, for higher levels of prior experience in the focal industry, the positive relationship between prior entrepreneurial experience and choosing a niche market is dampened, not strengthened.

Table 3-3 Cox proportional-hazard regression model (Niche Market=1)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Prior Technical Experience		0.780			0.361			0.379
		(0.000)			(0.000)			(0.000)
Prior Market-Related Experience			1.518			0.346		0.293
			(0.037)			(0.000)		(0.000)
Prior Entrepreneurial Experience				1.212			1.553	1.181
				(0.013)			(0.000)	(0.000)
Prior Tech. x Prior Focal Experience					7.284			5.793
					(0.000)			(0.000)
Prior Market-Rel. x Prior Focal Exp.						8.173		9.706
						(0.000)		(0.000)
Prior Entr. x Prior Focal Exp.							0.571	0.622
							(0.000)	(0.045)
Prior Solar-PV-industry Experience	1.612	1.674	1.499	1.493	0.317	1.070	1.992	0.329
	(0.000)	(0.000)	(0.000)	(0.000)	(0.005)	(0.239)	(0.000)	(0.000)
Vertically Integrated	0.984	0.981	0.980	0.998	0.992	0.882	1.016	0.894
	(0.713)	(0.633)	(0.438)	(0.972)	(0.578)	(0.010)	(0.786)	(0.000)
Gov. Financing	1.200	1.169	1.207	1.195	1.270	1.252	1.203	1.321
	(0.137)	(0.178)	(0.169)	(0.154)	(0.039)	(0.111)	(0.121)	(0.017)
VC Financing	0.983	0.983	0.983	0.983	0.978	0.981	0.983	0.975
	(0.032)	(0.030)	(0.036)	(0.035)	(0.108)	(0.076)	(0.042)	(0.183)
Technology Development Stage =2	0.299	0.284	0.301	0.305	0.359	0.316	0.282	0.333
	(0.075)	(0.072)	(0.050)	(0.087)	(0.049)	(0.040)	(0.071)	(0.035)
Technology Development Stage =3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(.)	(0.000)	(.)	(0.000)	(.)	(0.000)	(.)	(.)
Company size	0.892	0.934	0.872	0.903	0.676	0.845	0.918	0.687
	(0.685)	(0.810)	(0.555)	(0.721)	(0.000)	(0.363)	(0.758)	(0.000)
No. of Patents	2.018	1.926	2.148	2.080	2.797	2.146	1.963	2.705
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Size of niche (Cum. MW)	1.014	1.016	1.018	1.018	1.016	1.014	1.050	1.038
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(.)	(0.000)
Cum. Production of TF Tech	0.984	0.981	0.979	0.979	0.981	0.983	0.949	0.960
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
No. Niche companies	10.484	8.391	8.691	10.025	12.091	11.390	0.968	2.760
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(.)	(0.000)
No. Niche companies^2	1.000	1.006	1.007	1.007	1.003	1.001	1.062	1.041
	(0.305)	(0.000)	(.)	(0.000)	(0.000)	(0.000)	(.)	(0.000)
Year Dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	276	276	276	276	276	276	276	276
Log-Likelihood	-171.6	-171.5	-171.3	-171.5	-170.1	-170.2	-171.3	-168.7

Note: p-values in parentheses

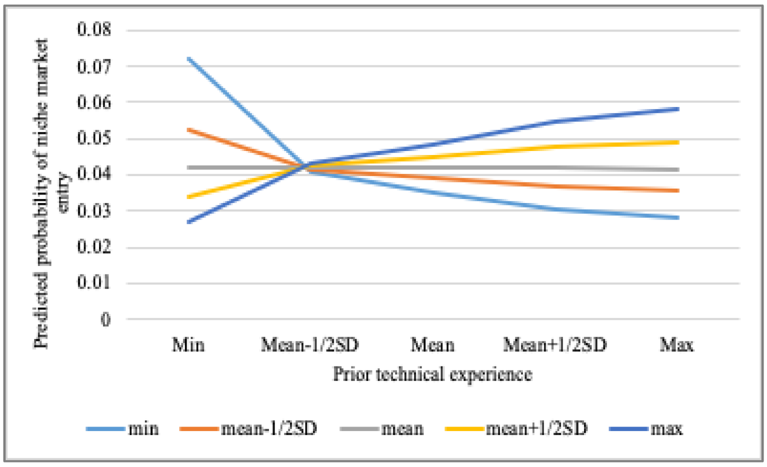


Figure 3-1 Graph of the moderating effect of prior experience in the focal industry on prior technical experience

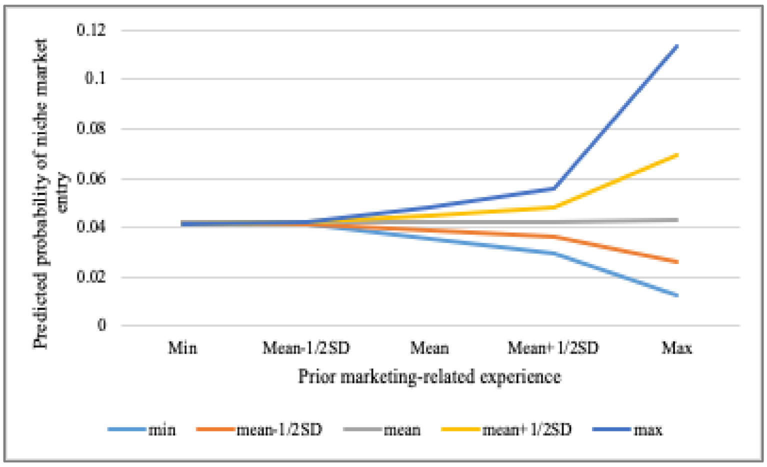


Figure 3-2 Graph the moderating effect of prior experience in the focal industry on prior marketing-related experience

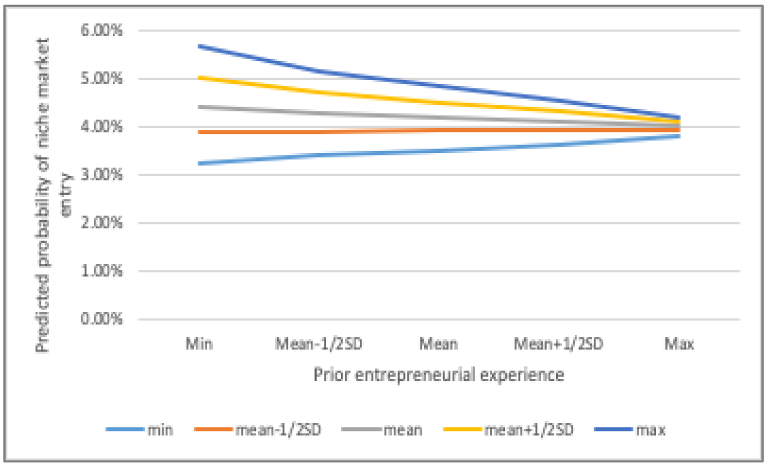


Figure 3-3 Graph the moderating effect of prior experience in the focal industry on prior entrepreneurial experience

3.4.1. Robustness Checks

We conducted a number of analyses to test the robustness of the results. First, we compared the results from the main analysis to results using a Logit specification, which corroborates the patterns found in the main analysis. Second, we re-run our models measuring prior experience using dummy variables taking a value of 1 if at least one member of the venture team has the specific type of experience, 0 otherwise. The results are consistent with the findings we report. Third, the results are robust to alternative specification of the financing that ventures received before choosing which product market to enter. Results are robust to measuring whether the venture has raised financing rather than the amount and type of financing and they are robust to measuring the total rounds of financing raised rather than amount and type of financing. Finally, we re-run our analysis controlling for the number of years from industry inception rather than including year dummies and results are consistent with the findings reported.

3.4.2. Alternative explanations

In describing our theory earlier, we suggested that the decision to enter a niche market is influenced by the prior functional experience of the venture team. The mechanisms we suggested highlight that, in the case of technical and marketing-related roles, prior experience in specific roles influences how individuals frame technology development, and whether they are familiar with challenges upstream or downstream in the value chain. It also equips individuals with prior entrepreneurial experience with preferences with regards to the characteristics of the opportunity to pursue.

However, when individuals have gained their prior experience in the focal industry, our results could be driven by some alternative explanations. Extant research on individuals having prior experience in the focal industry and their strategic choices shows that individuals are likely to choose strategy elements with which they already have direct experience (Fern et al., 2012). In our specific case, this means that venture teams would choose niche markets because the incumbent (in the solar PV industry) where individuals gained their experience had pursued a niche market rather than because of functional experience as we posited.

In order to explore this alternative explanation, we created a subsample including all the ventures in which at least one member of the venture team has prior experience in the solar PV industry. We re-run our analysis including an additional variable controlling for the case in which members of the venture team had gained their prior experience in a firm operating in a niche product market of the solar PV industry. This variable (*parent market niche*) is operationalized as a dummy variable taking the value of 1 when the incumbent was operating in a niche market in the solar PV industry, 0 otherwise. Results are reported in Table 4.

Model 1 introduces all the control variables including parent market niche. In line with the prediction by Fern et al. (2012), the coefficient associated with this variable is positive (β=1.414, p-value=0.152), albeit not significant. Model 2 introduces the variables measuring prior experience in different roles. In line with the findings from the interaction effect and Figure 1, the coefficient associated with prior technical experience is positive (β=1.084, p-value=0.628), yet not significant. The coefficient associated with prior marketing-related experience is positive (β=1.594, p-value=0.000) and the coefficient associated with prior entrepreneurial experience is negative (β=0.880, p-value=0.000) in line with the results of the interaction effect and Figure 3.

The results from this analysis suggest that prior marketing-related experience is positively associated with choosing a niche market even when controlling for direct prior experience in a niche market of the solar PV industry. Thus, it is more general prior experience in a role related to exploring markets that leads ventures to choose niche markets rather than specific experience in these markets. We also find a negative effect for prior entrepreneurial experience, further substantiating the result we found for H4c in the main analysis.

A second potential alternative explanation exists for individuals who are serial entrepreneurs in the industry. Prior research on serial entrepreneurship has shown that failure in a prior venture increases the likelihood that the entrepreneur will attribute the failure to external factors and change industry for subsequent entrepreneurial efforts (Eggers & Song, 2015). A similar argument can apply to the choice of markets. A serial entrepreneur who has had a prior failure in mainstream product markets may be more likely to choose niche product markets because he/she attributes the reason of his/her failure to the conditions in the mainstream market.

To rule out this alternative explanation, we created another subsample of ventures whose team has at least one member with prior experience as an entrepreneur in mainstream markets of the solar PV industry As this sample includes only 16 ventures, we present some statistics as evidence that when team members have previously failed as entrepreneurs in a mainstream market in the solar PV industry, they are not more likely to choose a niche a market than venture teams where members have not previously failed in the mainstream market. In our sample, there are only three ventures in which a member has a previous entrepreneurial failure in a mainstream market, and none enter a niche market (see Table 5). While we cannot completely rule out the likelihood that prior entrepreneurial failure in mainstream markets may lead to subsequent niche market entry, we show that in our sample this is not likely to happen, giving us some confidence that this alternative explanation may not apply in our context.

Finally, many of the niche markets in the solar PV industry emerged at the intersection of the solar PV industry and other industries such as the construction or the roofing industry for BIPV. Prior research finds that prior experience in upstream related industries influences the ability to make technological choices (Adams, Fontana, & Malerba, 2019; Furr et al., 2012). Similarly, prior experience in industries that are related to the focal industry from a market or user perspective can lead ventures to make specific market choices (Adams et al., 2016;

Shermon & Moeen, 2020). In our case, prior experience in industries that are related to niche markets from a user perspective could drive the venture's choice of niche markets.

To exclude the possibility that the venture's choice of niche market is driven by prior experience in industries related to niches rather than by prior experience in a specific role, we collected further data on the industries in which individuals gained their prior experience and coded when these industries are related to the solar PV industry (from a market perspective). We re-run our analysis controlling for prior experience in industries related to niches. Model 2 in Table 6 presents the results for this analysis. The results for prior technical experience, prior marketing-related experience and prior entrepreneurial experience are consistent with results from the main analysis. The coefficient for prior technological experience is negative (β=0.803, p-value=0.000) in line with Hypothesis 1. The coefficient associated with prior market-related experience is positive (β=1.523, p-value=0.038) and in line with Hypothesis 2. Finally, prior entrepreneurial experience is positively associated with choice of niche markets (β=1.161, p-value=0.084).

Table 3-4 Effect of prior experience in a parent company operating in a niche market in the solar PV industry on the choice of the venture (Niche Market=1)

VARIABLES	Model 1	Model 2
Prior Technical Experience		1.084
		(0.628)
Prior Marketing-Related Experience		1.594
		(0.000)
Prior Entrepreneurial Experience		0.880
		(0.000)
Parent Market Niche	1.414	1.528
	(0.152)	(0.197)
Vertically Integrated	1.043	0.954
	(0.836)	(0.863)
Gov. Financing	-	-
VC Financing	1.008	1.006
	(0.000)	(0.000)
Technology Development Stage =2	0.043	0.056
	(0.000)	(0.000)
Technology Development Stage =3	0.000	0.000
	(.)	(.)
Company size	0.185	0.198
	(0.000)	(0.000)
No. of Patents	26.100	23.875
	(0.000)	(0.000)
Size of niche (Cum. MW)	1.049	1.028
	(0.000)	(0.000)
Cum. Production of TF Tech	0.950	0.970
	(0.000)	(0.000)
No. Niche companies	121.535	2.303
	(0.000)	(0.000)
No. Niche companies^2	1.029	1.029
	(0.000)	(0.000)
Year Dummies	Yes	Yes
Observations	119	119
Log-Likelihood	-47.57	-47.42

Note: p-values in parentheses

Table 3-5 Tabular summary of product market choices for ventures whose team members have prior experience as entrepreneurs in the solar PV industry and have failed in the mainstream market

	Choice of Product Market		
Prior Entrepreneurial Failure in Mainstream Markets	**Mainstream**	**Niche**	**Total**
No	8	5	13
Yes	3	0	3
Total	**11**	**5**	**16**

Table 3-6 Effect of prior experience in an industry that is related to niche markets in the downstream part of the value chain (Niche Market=1)

VARIABLES	Model 1	Model 2
Prior Technical Experience		0.803
		(0.000)
Prior Marketing-Related Experience		1.523
		(0.038)
Prior Entrepreneurial Experience		1.161
		(0.084)
Prior Exp. in Industries related to Niches	0.973	1.001
	(0.252)	(0.970)
Prior Solar-PV-industry Experience	1.614	1.459
	(0.000)	(0.000)
Vertically Integrated	0.982	0.989
	(0.664)	(0.679)
Gov. Financing	1.201	1.176
	(0.136)	(0.239)
VC Financing	0.983	0.984
	(0.031)	(0.037)
Technology Development Stage =2	0.299	0.292
	(0.075)	(0.060)
Technology Development Stage =3	0.000	0.000
	(.)	(.)
Company size	0.889	0.915
	(0.678)	(0.720)
No. of Patents	2.027	2.110
	(0.000)	(0.000)
Size of niche (Cum. MW)	1.019	1.021
	(0.000)	(0.000)
Cum. Production of TF Tech	0.979	0.976
	(0.000)	(0.000)
No. Niche companies	1.009	9.745
	(0.928)	(0.000)
No. Niche companies^2	1.027	1.010
	(0.000)	(0.000)
Year Dummies	Yes	Yes
Observations	276	276
Log-Likelihood	-171.6	-171.1

Note: p-values in parentheses

3.5. DISCUSSION

In this study, we examine how mainstream and niche markets present different challenges that affect commercialization choices on the product market. Going beyond industry level dynamics that generate heterogeneity in markets in terms of their attractiveness or competitiveness, we explore the role that prior experience plays in the decision to target a niche product market. Overall, we show that cognitive representations of decision makers not only play a role in how large companies react to new and disrupting technologies (Kaplan, 2008; Kaplan, Murray, & Henderson, 2003), they also affect the decisions of new ventures who are developing these potentially disruptive technologies to market.

We contribute to the literatures on disruption, market entry choice and to the cognition literature in entrepreneurship. The literature on disruption has largely focused on successful cases of disruption (Christensen & Bower, 1996; Marx et al., 2014), and proposes that novel technologies with disruptive potential will be commercialized by technical entrepreneurs who have the knowledge to further develop these technologies to fulfill hitherto unmet needs of end users in niche markets. In predicting that choosing a niche market is a key mechanism for disruption (Danneels, 2004), this literature assumes that niche markets are the preferred entry option for startups looking to commercialize novel technologies in the product market.

Our investigation into the cognitive underpinnings of venture team members' past experience on the choice of niche markets attempts to provide a more nuanced picture. We provide evidence that different types of past experience will focus venture teams' attention on specific problems in different parts of the value chain, thereby impacting in which market they commercialize their technology. On the one hand, venture teams with *prior marketing-related experience* and prior *entrepreneurial experience* prefer to address customer-related challenges downstream in the value chain and favor niche markets, in line with the predictions of the literature on disruption (Danneels, 2004). On the other hand, venture teams with *prior technical experience* surprisingly do not enact a niche strategy, do not appear to be attracted by end user needs and instead prefer to take on technical challenges upstream in the value chain. These findings hold after controlling for the acquisition of venture capital, which might come with certain logics that move entrepreneurs away from niche markets as suggested by Pahnke et al.

(2015). We also find that the preference to target a mainstream market becomes less pronounced when the technically experienced venture team has also acquired prior experience in the focal industry. It is possible that the prior industry experience equips them with deeper insights into the strategic reactions of the incumbents in the industry and into the role of application for technical development so that they are better positioned to evaluate their chances of successful commercialization in mainstream markets. By highlighting the multifaceted nature of the market entry choice for ventures in their new technology commercialization effort, we begin to provide some insight into why disruption is so rarely seen (Finkelstein & Sanford, 2000).

Our results also inform the literature on market entry choice which has examined the decision to license versus commercialize on the product market. Recent work has highlighted that new entrants typically do not choose to license, but rather prefer to commercialize in the market for products (Peters & Thiel, 2016). In line with their findings, we also conclude that, in the solar PV industry, ventures had a clear preference for entering the product market over licensing. The literature on market entry choice posits that commercialization on the product market takes place when the complementary assets necessary for commercialization are not controlled by incumbents (Arora & Ceccagnoli, 2006; Colombo, Grilli, & Piva, 2006; Teece, 1986) and/or when the appropriability regime is weak. Extant work on market entry choice takes homogeneity of product markets within an industry for granted and assumes that the conditions for successful commercialization on the product market are the same within the industry. We show that the existence of multiple sub-markets in an industry renders the market entry choice more complex than previously assumed because commercialization challenges in the different types of sub-product markets in the industry may not be the same. Thus, we join the conversation on the renewed interest of strategy scholars in understanding within-industry market differences (Uzunca, 2018).

Building on current work on market entry choice, one would expect that new entrants would preferably enter niche market segments where complementary assets are not consolidated or controlled by incumbents. We find that ventures with prior technical experience gained outside the focal industry nevertheless enter mainstream markets where complementary assets are consolidated and co-specialized to the old technology. Such an entry decision cannot be explained by market structure. We explain this choice by adopting a cognitive lens (Gavetti & Rivkin, 2007), which suggests that cognition plays a central role in entrepreneurial decision making (Shepherd, Souitaris, & Gruber, 2020), and offers a complementary perspective to the economic view, which contends that industry structure is the main determinant of strategic action (Nadkarni & Barr, 2008). We show that the cognitive preferences of venture teams with prior technical experience focus their attention on technology-related challenges in the upstream part of the value chain. This leads them to make decisions that do not align with current explanations from the literature on market entry choice that focus on the structure in the downstream product market and availability of complementary assets to explain the choice of product commercialization.

Finally, we contribute to the cognition literature in entrepreneurship, which has shown that pre-entry experience in the founding team has a lasting impact on the product market choice of ventures (Fern et al., 2012) and their innovation strategy (Furr, 2019). The overall conclusion in this literature is that deeper experience within a certain market or industry leads to more constrained and less innovative strategic choices because of structured cognitive maps that reflect the expertise in a certain domain (Dane, 2010). We examine both functional expertise (technology or marketing) and contextual expertise (in an industry specific domain) and show that contextual experience within an industry may have a relaxing effect on the cognitive rigidities that stem from pre-defined prototypes accompanying technical functional expertise. In other words, within-industry experience tempers the rigid focus of technically adept founders to solve technology problems facing incumbents in mainstream markets and guides them towards niche markets. Such experience in the industry allows technical founders to be more attentive to informational cues available in marginal markets and to connect the dots regarding what niche users might appreciate in their technology (Furr et al., 2012).

Our examination of the role of marketing-related vs niche market-specific experience further nuances our understanding of the role of marketing experience. While product market-specific experience is associated with focusing on current customers and constrains ventures to choose the same market over time (Fern et al., 2012) creating a knowledge corridor for ventures (Gruber et al., 2013), ventures that have developed a higher order marketing experience and are skilled at assessing markets and gaining access to market-related resources (Danneels, 2008) are open to attend to the needs of emerging customers and enter niche product markets even when they do not have direct experience with these markets.

Finally, our findings related to technical and marketing experience point to a trade-off between the number of markets and the type of markets identified for technology commercialization. Even though marketing experience has been found to create a cognitive corridor constraining founders from identifying a variety of alternative opportunities (Gruber et al., 2012), we find that marketing-related experience points ventures towards product markets that enable more disruptive strategies. On the contrary, greater technical experience allow founding teams to better leverage their industry experience and identify a wider variety of applications (Gruber et al., 2013). However, since technical teams typically choose mainstream markets populated by large incumbents, technical prior experience does not lead ventures to those applications that can be the starting point for a disruptive trajectory.

3.5.1. Limitations and future research

Like any study, this one is not without limitations. First, we need to be cautious in terms of generalizability as we explored our research question in one industry. Future work could explore the relationships we theorized in other industries to generalize findings and develop further insight into the choice of niche product markets. Second, in this study, we focus on the impact of different types of experience and whether they were accumulated in the focal industry. Thus, we have only scratched the surface of the effect of prior experience on the choice of niche product markets. Future work could examine how the interplay of different types of experience influences the choice of niche markets. Similarly, future research can further explore the role of knowledge along the value chain on product market choices.

While outside the scope of this study, product market choices carry consequences for both the ventures making them and the industry as a whole. Future research could explore the consequences of product market choices in terms of development of strategies and capabilities as well as venture's survival.

3.6. CONCLUSION

In conclusion, by studying the impact of prior experience of the venture team on the decision to enter a niche product market, we underscore the importance of taking a cognitive view of potentially disruptive technologies and show that cognition affects not only incumbents facing disruption but also the ventures spearheading it. Our findings on teams with strong technical background shed light on the reasons why few ventures in high technology industries choose niches and why disruption rarely happens. The findings on marketing experience adds nuance to our current understanding of whether function-specific experience constrains choice. Finally, we point to a trade-off between the number of potential markets identified and the ability to recognize and enter markets that can lead to disruption.

4. ENTRY INTO MISFIT MARKETS: EVIDENCE FROM THE SOLAR PHOTOVOLTAIC INDUSTRY

Abstract

Ventures that choose the wrong market for their technology put their commercialization efforts and survival at risk. Despite the scale of these risks, many ventures still make this choice and we still know little about the conditions leading ventures towards misfit markets. . In this chapter, I leverage the concept of demand heterogeneity and the existence of heterogeneous criteria for evaluation in different markets to define misfit markets as those markets in which there is a mismatch between the attributes along which the technology performs well and the attributes valued by customers. I explore how increasing capital availability affects ventures' interpretation of the demand landscape and their entry into misfit markets. I also explore the ability of industry spinouts to better sustain the increased cognitive load generated by increased capital availability. Findings from the global solar photovoltaic industry support the idea that increasing capital availability generates a widespread bias in the industry – which I term a "hyped up" demand landscape – that affects the ability to gather and interpret information about demand and explain why ventures choose markets in which customers do not value the functionalities offered by the technology commercialized. At the same time, they show that industry spinouts see past these biases and make more objective choices.

4.1. INTRODUCTION

From misallocated resources and failed commercialization to a threat to the very existence of the venture itself, choosing the wrong market holds many risks for entrepreneurial ventures (Molner, Prabhu & Yadav, 2019; Shane, 2004). Yet, entrepreneurship accounts are ripe with stories of ventures that made this choice. For example, Anki was a robotics start-up that raised more than $ 200 Millions from reputable ventures capitalists such as Andreessen Horowitz and planned to sell its robots as toys for young children. Yet, it failed to recognize that, despite the sophisticated software, their robots could not be played with or could not entertain for a long time, two crucially important characteristics for toys. In the long run, this turned them into a spectacular and costly failure in 2019. Anki is not alone in deciding to target a market that would not appreciate its sophisticated technology. A report by Quake Capital, a start-up accelerator and early-stage VC firm, finds that almost 50% of venture failures can be partly attributes to a lack of market interest or products that do not match what customers want (quakecapital.com, 24 June 2018).

Despite the pervasiveness of this phenomenon and its associated risks, we still know surprisingly little about the conditions that lead entrepreneurs to make this choice and enter misfit markets, i.e. markets in which there is a mismatch between the attributes along which the technology performs well and the attributes valued by customers. In this paper, I respond to this gap by addressing the question: *what drives entrepreneurial ventures to choose markets with a low technology-market fit?*

Extant work examining how entrepreneurial ventures choose a market for technology commercialization relies heavily on the concept of technology-market linking. This is a cognitive process of market search in which ventures identify and evaluate potential technology-market pairs to form opportunities (Grégoire and Shepherd, 2012; Gruber, MacMillan & Thompson, 2008). Much of the prior literature has, however, focused only on the first step – the identification of potential technology-market pairs – and has posited that identifying more potential markets will eventually bring more positive outcomes to the venture such as superior sales performance and higher value appropriation (Danneels, 2007; Gruber et al., 2008). Yet, extant scholarship has paid less attention to the second step of the technology-to-market linking[4] process – the evaluation of potential technology-market pairs. Linking the identification of more markets to successful outcomes seems to suggest that all market identified are equally promising. However, this ignores that not all markets evaluate technologies the same way and we do not know whether such successful outcomes were reached only after entrepreneurs tried their luck with several different markets. This makes the second step - evaluation - crucial for ventures to fully realize the predicted positive outcomes and deserving of more academic attention.

I leverage the literature on demand heterogeneity and the concept of demand landscape (Adner & Levinthal, 2001) to examine how industry-level factors affect the cognition of all ventures in the industry and the likelihood that they enter a market with poor fit, i.e. a market in which the functionality offered by the technology does not match the functionality attributes valued by the customers. Furthermore, I explore whether specific characteristics of ventures support their cognition in linking technologies to markets.

While extant work has focused on internal knowledge endowments (Grégoire and Shepherd, 2012; Gruber et al., 2008; Gruber, MacMillan & Thompson, 2013), ventures do not act in a vacuum. Their cognitive processes and decision making are also influenced by external factors, something that the literature has only recently begun to highlight (Benner & Tripsas, 2012). Industry-level factors influence the availability of high-quality information about demand, which is critical for the evaluation of markets. Thus, they take center stage when studying why ventures enter markets with poor technology-market fit.

[4] In this chapter, I use the terms technology-market linking and technology-to-market linking interchangeably.

I argue that industry-level factors can either obscure or shine light on the demand landscape, making it appear either less or more accurate. Thus, they either hide or reveal demand-side information and, in the process, they respectively create or reduce cognitive biases that affect how cognitively taxing the process of technology-market linking is.

I examine the role of increasing prior capital availability in the industry as a key factor belonging to the first category (factors that obscure the demand landscape). I argue that capital availability creates a cognitive bias in the form of a "hyped-up" demand landscape that does not reflect the real one anymore but one in which ventures believe. This bias leads ventures to enter markets where their technology does not match the requirements of customers.

I also explore the intersection between industry-level factors and ventures' characteristics. I argue that industry spinouts have specific knowledge and focus that equip them with superior cognitive abilities that enables them to better withstand the conditions created by the increasing capital availability, i.e. the "hyped-up" demand landscape. Thus, they make more objective choices during times of increased cognitive load.

The empirical setting for this study is the global solar PV industry. This is a suitable context to study my research question for several reasons. On the supply side, there are three technology generations populating the industry. These three generations vary in terms of which functionality attributes they offer and how well they perform along these attributes. On the demand side, the solar PV industry offers multiple markets in which to commercialize a technology. Each market differs in terms of which functionality attribute(s) it values, how they are ranked and how well the technology is expected perform on each attribute. This demand-side heterogeneity and the associated varied demand landscape make the solar PV industry a particularly appropriate context for my study. To perform my analysis, I collected a detailed dataset on all market choices made by all ventures that entered the solar PV industry to commercialize one of its generations of solar technologies. I identified 433 instances of market choices made by 245 ventures. I complemented this dataset with qualitative work to gain a deeper understanding of the industry and to qualify my results.

I find support for the idea that increased capital availability leads ventures to make more choices with poor technology-market fit. I also find support for the idea that industry spinouts can better sustain the increased cognitive load created by the "hyped-up" demand landscape and are less likely to choose misfit markets during times of capital munificence.

With this study, I contribute to the literature on technology commercialization of entrepreneurial ventures, entrepreneurial cognition and venture capital. I show that the phenomenon of choosing markets with poor fit is pervasive in the solar PV industry and I show that the decision to enter such markets is driven by a cognitive bias at the industry level. I also show that entry into poorly fitting markets does not equate entry into resource-rich markets as is pointed out by the literature on entrepreneurial herding behavior (Pontikes & Barnett, 2017; Barnett, Swanson & Sorenson, 2003). For the literature on entrepreneurial cognition, I illuminate the role played by factors external to the ventures in creating biases and affecting cognition of the venture. I, thus, join recent research that has begun to explore the role of external factors on firm cognition and decision making (Benner & Tripsas, 2012). I also highlight another advantage of industry spinouts, i.e. ability to sustain increased cognitive load associated with technology-market linking during times of resource munificence, that can contribute another explanation to their survival advantage identified by prior research (Agarwal et al., 2004; Agarwal & Shah, 2014). Finally, I point to the potential negative effect that venture capital investment can have on ventures other than the investees and on markets.

4.2. THEORY DEVELOPMENT AND HYPOTHESES

Technology start-ups are a source of innovation and wealth creation (Schumpeter, 1934; Shane, 2004). Their choice of a market is the first step to unleash such potential. As technologies can create value in multiple industries and multiple sub-markets within an industry (Penrose, 1959), choosing a market for technology commercialization is far from straightforward. At the same time, the decision of which market to target is highly consequential as it affects which resources and capabilities ventures need to develop (Fern et al., 2012; Porter, 1985) and, eventually, it will affect the venture's ability to commercialize its technology as well as its ultimate survival (Dahl & Sorenson, 2012; Gruber et al., 2008). This makes the ability to identify and choose markets a critical, yet elusive, skill for entrepreneurs (Danneels, 2007; Molner et al., 2019).

Existing scholarship offers useful insights on how the process of choosing a market for technology commercialization unfolds. This prior work relies heavily on the concept of technology-to-market linking to study how ventures make decisions regarding which market(s) to target (Grégoire & Shepherd, 2012). At its core, technology-market linking is a cognitive process of "market search" involving local and distant search regarding demand. It involves the combination of technological knowledge with the information gathered on demand to identify and evaluate potential technology-market pairs (Gruber et al., 2008, Shane, 2000).

Relying on this process of technology-to-market linking, extant work has begun to unpack the antecedents to and the consequences of identifying a large number of potential technology-market pairs. Prior work in the first line of inquiry gives us a key understanding of the role of founders' experience endowments and of founders' willingness to acquire knowledge from partners on the identification of potential markets (Grégoire & Shepherd, 2012; Gruber et al., 2008; 2013; Gruber, MacMillan, & Thompson, 2012; Shane, 2000). For example, Gruber and colleagues offer theoretical and empirical support for the different roles played by specialized and general experience on the ability to identify larger sets of potential markets (Gruber et al., 2012; 2013). They find that general experience, e.g. managerial and entrepreneurial experience, endows venture teams with holistic knowledge which unlocks cognitive flexibility, thus facilitating the identification of multiple potential markets for the same technology (Gruber et al., 2008). In contrast, experience in specialized roles, such as technical and marketing roles, reduces cognitive flexibility and constrains the identification of multiple potential markets (Gruber et al., 2008; 2012).

Extant research also provides key insights on the consequences of technology-market linking. This line of inquiry finds that ventures that generate larger sets of potential technology-market pairs are more likely to diversify over time (Gruber et al., 2013). Moreover, the identification of larger sets of potential markets leads to better performance in terms of sales revenues (Gruber et al., 2008) and value capture (Danneels, 2007).

Despite providing these key insights, extant work has largely focused on the first step of the linking process and on the ability to identify larger sets of potential markets. By overly focusing only on the first step of technology-market linking and by associating positive outcomes to the identification of larger sets of potential markets, this literature suggests that every market identified is equally promising and that it offers the same chances of success. This suggestion, however, neglects to consider the qualitative differences among markets and how these differences can severely impact the commercialization process and its outcomes. In fact, it has long been recognized by the literature on demand-side strategy that the demand environment in an industry is not homogeneous and each application domain (market) within an industry differs widely in terms of technology evaluation (Adner & Levinthal, 2001, Priem, Li and Carr, 2012).

Moreover, linking the identification of more markets to successful outcomes also neglects that the path to successful outcomes is not always straightforward. To reach the predicted success, entrepreneurs may have had to attempt technology commercialization in several markets sequentially and pivoted to new markets over time before reaching a promising market and success. Thus, the second step of the technology-to-market linking process, i.e.

evaluation of potential technology-market pairs, becomes crucially important for ventures to successfully commercialize their technology and reach the predicted positive outcomes. As such, it deserves more scholarly attention.

In this paper, I explore this gap and ask the following research question: *what drives entrepreneurial ventures to choose markets with a low technology-market fit?* Given the importance of fit between a firm's resources and its environment (Sirmon, Hitt, & Ireland, 2007) and the predicted risks associated with the choice of a poorly fitting market (Molner et al., 2019; Shane, 2004), it is important to understand why ventures would make such a choice.

To answer this question, I leverage the literature on demand-side strategy (Priem et al., 2012) and I rely on the concept of demand landscape (Adner and Levinthal, 2001) to examine the role of increasing capital availability and of ventures' characteristics such as being an industry spinout on the choice of misfit markets, i.e. markets in which there is a mismatch between the attributes along which the technology performs well and the attributes valued by customers. These two factors – investment availability and being an industry spinout – have been found to play a key role on entrepreneurial behavior and on technology commercialization (Pontikes & Barnett, 2017; Valliere & Peterson, 2004; Klepper, 2002 b; Klepper & Sleeper, 2005). In this paper, I argue that they play a critical role on the choice of misfit markets.

The evaluation of technology-market pairs involves careful interpretation of information about demand and, thus, hinges on the availability and quality of this information. As such, industry-level factors that affect the availability, quality and prominence of demand-side information, such as capital availability, will necessarily play a role on the ability to evaluate markets (Bogner & Barr, 2000). Recent work on entrepreneurial cognition provides initial evidence supporting the view that factors external to the venture impact its cognition and its processes and has explored the influence of stakeholders' cognition on innovation (Pahnke, Katila & Eisenhardt, 2015) and the influence of decisions of other ventures in the industry on product design choices (Benner & Tripsas, 2012).

At the same time, evaluation of markets is a cognitive process and, thus, depends on the individuals within the firms (Alvarez & Busenitz, 2001), the attention they bestow upon different information cues and their ability to interpret them (Ocasio, 1997). The process of alignment involved in technology-market linking and evaluation is not the default reasoning mode of individuals and, as a consequence, is cognitively burdensome (Grégoire & Shepherd, 2012). Thus, ventures will be differently endowed to engage in this process based on differing cognitive abilities.

4.2.1. Demand heterogeneity: the reason for technology-market fit

The demand-side view of strategy has emphasized the importance of customer preferences and product markets for the evaluation of a technology (Adner & Levinthal, 2001; Levinthal, 1998), the creation of value (Priem, 2007; Priem et al., 2012) and technological change (Tripsas, 2008). One of its tenets is that customers are heterogeneous in their preferences and that such heterogeneity affects firms' strategic decisions and their consequences (Priem, 2007; Adner, 2002).

As customers evaluate technologies based on their goals (van Osselaer et al., 2005), they vary in the criteria they use for technology evaluation and, as a consequence, different application domains (markets) have different bases for the selection of what is relevant in the domain (market) (Levinthal, 1998).

This heterogeneity in criteria for technology evaluation in the industry is the reason why technology-market fit exists. As markets differ in the functionality attributes that they consider important, each market will evaluate the same technology differently. As a consequence, the same technology will be considered high performing in some markets, while its performance will be deemed lacking in others. It follows that each technology-market pair will present varying levels of fit based on how the technology performs along different functionality attributes and on markets' preferences for these attributes. Thus, I define misfit markets as those markets in which there is a mismatch between the attributes along which the technology performs well and the attributes valued by customers in those markets. The representation of markets in an industry and the functionality attributes they deem important forms the demand landscape (Adner & Levinthal, 2001).

I define markets around the application (product) offered (Adner & Snow, 2010; Klepper & Thompson, 2006). This definition of markets aligns with prior research that has defined markets as specialized product clusters that can be differentiated by the product offered (Klepper & Thompson, 2006) and is in line with prior studies examining firm's positioning within an industry (Adner & Snow, 2010; de Figueiredo & Silverman, 2007) and industry evolution (Uzunca, 2018). Moreover, it is also in line with goal-setting categorization and evaluation based on functionality (van Osselaer et al., 2005).

I use the concept of demand landscape to explore the role of industry-level factors on the chances that ventures enter a market with poor technology-market fit.

When there is substantial uncertainty regarding which functionality attributes that a technology can deliver (Abernathy & Clark, 1985; Tripsas & Gavetti, 2000), which markets exist and which functionality attributes they value (Adner and Levinthal, 2001), industry-level factors can play a key role in revealing the existence of new markets or information about how they evaluate a technology. Thus, they offer important cues regarding the demand landscape that affect how cognitively taxing the technology-to-linking process can be.

In this paper, I focus on industry-level factors that make the technology-market linking process more taxing. I argue that some factors shine lights only on certain parts of the demand landscape and, thus, obscure other parts and the demand-side information coming through from those parts. They constrain the ventures' ability to accurately see and judge demand-side information, creating widespread biases that prevent ventures from accurately seeing which markets exists and what criteria is used to evaluate technology in each market. Thus, they make it harder for ventures to evaluate the fit between their technology and potential markets. I explore the role of increasing prior capital availability in obscuring parts of the demand landscape and increasing the chances that entrepreneurial ventures choose misfit markets.

4.2.2. Increasing prior capital availability

Prior work on investment cycles has found that increased capital availability influences entrepreneurial behavior as entrants become more likely to herd into certain markets(Pontikes & Barnett, 2017; Valliere & Peterson, 2004). Thus, as more and more VC investment is poured into an industry, industry participants and industry observers pay disproportionately more attention to some markets while ignoring others. When attention is cast only on certain parts of the demand landscape, the availability and quality of information about the real demand landscape deteriorates. Markets that receive little capital become cognitively invisible to ventures gathering demand information and the attributes valued by the markets that receive the most capital become overemphasized while the existence of other attributes of the technology and their roles for different markets loses importance.

Capital availability, thus, affects the quantity and quality of demand-side information available for the technology-market linking process and can impact the extent to which this process is cognitively taxing for ventures (Grégoire & Shepherd, 2012). This happens through the creation of a widespread cognitive bias in the form of a "hyped-up" demand landscape that does not reflect the real one anymore. The bias involves both (1) ignorance that some markets exists and (2) the belief that markets value some functionality attributes even though they really value some other attributes. Thus, ventures attempting to choose a market for their technology become less aware of demand heterogeneity.

The creation of a "hyped-up" demand landscape is the first step to entry into markets with poor technology-market fit. The more capital is available in the previous period, the more ventures will become overly confident in the outlook of the industry and of their own ventures. Thus, ventures will dedicate less time and effort to the market search and the "hyped-up" demand landscape will become cognitively entrenched.

Thus, the belief in a "hyped-up" landscape that does not reflect the real demand heterogeneity coupled with ventures overconfidence and lower cognitive effort for technology-market linking will lead ventures to enter markets with poor technology-market fit while believing they are making a sound choice.

Hypothesis 1 (H1): *The greater the capital availability in the industry in the previous period, the more ventures enter into markets with poor technology-market fit.*

4.2.3. The role of industry spinouts

The evaluation of potential technology-market pairs also depends on the ability of ventures to interpret demand-side information and to sustain the cognitive load involved with the technology-market linking process (Grégoire & Shepherd, 2012). The ability to identify specific cues is often context specific (Ocasio, 1997) and existing work has found that perceptions vary across industry contexts (Priem, 1994; Nadkarni & Barr, 2008). Thus, the industry in which the venture was incubated likely play a role in a venture's ability to sustain the increased cognitive load generated by increasing capital availability. Prior research underscore that incubation in the same industry, as it happens for industry spinouts, equips ventures with knowledge and skills that are critical for their survival (Agarwal & Shah, 2014; Klepper, 2002; Klepper & Sleeper, 2005).

Industry spinouts are ventures founded by employees of existing firms in the industry who leave the incumbent firm to found another venture in the same industry (Agarwal et al., 2004: Klepper, 2002 b). Given their incubation environment in the industry, spinouts possess an improved understanding of structural features of industry-specific problems (Chi, Glaser, & Farr, 1988) and are capable of integrating more disparate informational cues (Eisenhardt & Bingham, 2017). As the understanding of structural features lies at the heart of the technology-market matching process and of market evaluation (Gregoire & Shepherd, 2012), industry spinouts are perfectly positioned to interpret information necessary for technology-market linking with more ease. This happens through two key processes.

During their time at the parent firm, founders have learnt about technical and market opportunities of the industry (Agarwal et al., 2004). Thus, they are more aware of the existence of different markets and of the functionality attributes valued in each of them, i.e. they are more aware of the structure of the demand landscape (Adner & Levinthal, 2001).

Industry spinouts also possess operational knowledge that is more focused on turning technologies into products compared to other types of ventures. In fact, their knowledge conversion capability, key for choosing markets, place more emphasis on embodiment and integration capabilities rather than other capabilities for technology commercialization (Zahra et al., 2007). Embodiment and integration capabilities refer to the ability to integrate different sources of knowledge in order to convert technology into a marketable product (Zahra et al., 2007). This emphasis makes spinouts more attentive to issues of technology-market linking. Thus, they are more aware of the challenges resulting from technology commercialization and of the importance of choosing markets where the technology is valued.

Their awareness of the structure of the demand landscape coupled with their emphasis on matching technologies to markets make industry spinouts better equipped at sustaining the cognitive process involved in technology-market linking. I argue that their superiority at the cognitive processes involved in technology-market linking will be particularly useful during times of increased capital availability when the cognitive demands involved with identifying the right market for their technology are increasing.

First, the superiority of their demand-side knowledge, which includes more awareness of different markets, of their underlying quality and of what each market values, make them more aware of what the true demand landscape looks like in the industry. For this reason, they are less likely to believe in the skewed information generated by increased capital availability and less likely to buy into the "hyped-up" demand landscape that other ventures believe in. Second, their focus on embodiment and integrations capabilities (Zahra el al., 2007) help them to better withstand the increased cognitive load generated by uncertain information on demand as created by investment waves. Thus, there are more likely to keep looking for reliable information when such information is hard to find.

Taken together, these arguments suggest that industry spinouts will be less affected by the conditions created by increased capital availability and they will be more objective in their valuation of the demand landscape and choice of product market. For this reason, they are less likely to choose markets with low technology-market fit during times of increased capital availability. Thus, I hypothesize that,

Hypothesis 2 (H2): *The positive relationship between capital availability and choice of markets with poor technology-market fit is negatively moderated for industry spinouts.*

4.3. DATA AND METHODS

4.3.1. Empirical context

I set my study in the global solar PV industry. The sample includes the entire population of entrepreneurial ventures that entered the industry to commercialize solar technologies, i.e. technologies that convert solar light into electricity. The definition used to identify solar ventures is in line with prior research on this industry (Furr & Kapoor, 2018; Hannah & Eisenhardt, 2018; Kapoor & Furr, 2015).

The solar PV industry is an appropriate context to study this research question. On the technology side, the industry is characterized by several technology generations that offer different performances on different functionality attributes. The first technology generation is based on silicon as a semiconductor material. This technology generation offers high efficiency and low costs. While they perform very well on efficiency and price, silicon-based solar cells are very heavy and rigid. The second technology generation – second-generation thin film –- relies on a different class of semiconductor materials, such as copper indium gallium selenide (CIGS), and new manufacturing methods. Solar cells in this technology generation have an advantage in terms of weight and flexibility.

Finally, the third generation of technology to emerge – third-generation thin film – relies on new classes of environmentally friendly materials, such as Copper Zinc Tin Sulfide (CZTS), polymers or organic materials, and new manufacturing methods, such as deposition or printing methods. While lacking in terms of efficiency, this generation can provide low cost alternatives and its strong suit lies in its transparency, weight and flexibility.

The solar PV industry is a particularly suitable context for my research question because it exhibits considerable heterogeneity on the demand side. Solar PV technologies can be commercialized in a number of different markets. There are four main categories of markets: rooftop systems, ground-mounted systems, building-integrated photovoltaics (BIPV) and integrated products such as chargers or lamps. During the data collection, I identified 19 unique application domains. Much of this diversity is in BIPV and integrated products where I find a multitude of specific applications such as solar tiles, solar windows or solar façades, but also internal solar applications (e.g. for Internet of Things - IoT).

Each domain values different functionality attributes. For example, rooftop and ground-mounted systems both value efficiency as the primary attribute to evaluate performance.

Ground-mounted systems also value cost primarily in order to build systems that can deliver strong ROI and be attractive for investors.

BIPV is mostly used for construction of green buildings. Customers are less sensitive to cost or efficiency but care deeply about weight, flexibility and transparency for construction and aesthetic reasons. There is also variety among the domains belonging to BIPV. For example, the domains of solar tiles or solar façades are not overly concerned with transparency, yet this attribute is paramount for solar windows/glass. Customers for integrated applications place high value on performance alongside cost, weight and flexibility, but they are not concerned with issues of efficiency. Finally, the market for internal PV (to power things such as IoT) is interested in performance in low-light conditions since it is used inside buildings.

4.3.2. Descriptive evidence of demand heterogeneity in the solar PV industry

In this section, I use qualitative evidence to show the existence of demand heterogeneity in the solar PV industry in terms of what customers valued in some of the markets existing in the industry. For example, ground-mounted systems are large-scale installations built to generate energy for the electricity grid. For this reason, they are often constructed by specialized asset management firms (EPC firms) that raise capital, build them and then operate them to generate a return on their investment. To raise capital at a lower cost and make a higher return on investment, these firms focus on efficiency and reliability. In one of the interviews I carried out, one of my informants discussed that "*there is a benefit to having a more efficient panel […] when you develop a solar park and you have to rent the field, the cost of renting obviously means that if you've got a high rent then it means that you want to be able to squeeze as much solar into the space*." (co-founder and executive director of EPC firm). Another informant shared that "*the more predictable the performance of the technology, the lower the return requirement the investor will have for investing in your project*" (CFO of development and asset management firm).

BIPV applications such as building façades or tiles placed high value on aesthetic and weight. Weight was key to increase PV-suitability since "*BIPV could increase these PV-suitable areas on buildings if products are lightweight or designed for specific building features*." (James, Goodrich, Woodhouse, Margolis, Ong, 2011). The CEO of Arch Aluminum & Glass Co discussed: "*Until today, aesthetic and performance concerns limited the ability of architects to use BIPV technology in their designs. This product development investigation is about the creation of a new product category, one that had been unavailable until today. It is energy-efficient and transparent with superior vertical performance and a subtle red, blue or green aesthetic. With these features, BIPV will no longer need to be confined to spandrel or overhead applications. An entire building can be put to use, producing its own power, and looking good doing so*." (Business Wire, 2009). Finally, a number of reports identified aesthetic and ability to blend in as key functionality attributes valued in BIPV (James et al., 2011; Zanetti, 2010). Table 2 in the Appendix shows further information on the criteria considered important in each market.

I also use qualitative evidence to show that ventures had different understanding of the demand landscape at different points in time. The first few years of the 2000s were characterized by relatively low investment into the solar PV industry. Ventures correctly identified the main functionality attributes that needed to be addressed in different markets. For example, when speaking about electronics, Heliovolt correctly determined that "*Electrical efficiency is not a factor as long as the PV modules produce enough to trickle charge a small, portable battery for low power electronics*." (Heliovolt.com, 19 November 2003). Similarly, Konarka recognized that weight and flexibility were key aspects for success in the market for military applications, the first application they targeted. They also recognized that access to other markets hinged on efficiency (Konarka.com, 17 February 2004).

Capital availability in the industry began to rise in 2005 and skyrocketed from 2006. During this period, ventures discussing markets and technologies showed a limited understanding of the demand landscape. Solopower appeared to neglect demand heterogeneity in general when discussing the solar PV industry: "*SoloPower's manufacturing process is aimed at addressing the two chief success criteria in today's solar energy market: cost and efficiency*." (Solopower.com, 12 July 2007). Konarka saw different markets in the solar PV industry but, unlike during the first few years of its existence, it now perceived the same functionality attributes for all markets, and therefore no longer perceived the real demand landscape: *"[We] provide a source of renewable power in a variety of form factors for commercial, industrial, government and consumer applications*" (Konarka PR, 8 January 2007). Yet, as the previous section shows, industrial applications such as ground-mounted systems were not particularly interested in form factors, i.e. design.

After the financial crisis, investment picked up again briefly in 2010 just to drop once more starting from the subsequent year. As investment rounds began to decrease, ventures recognized the variety of the demand landscape in the industry. For example, Solopower began discussing each market and their characteristics separately. Moreover, they highlighted the characteristics of ground-mounted systems valued by customers: "*Our CIGS-based modules prove to have the highest power density as compared to other technologies. [...] The combination of low installed cost and high-power density results in a low levelized cost of energy and superior financial returns for system owners*." (Solopower.com, 23 March 2012).

4.3.3. Sources and Data

The longitudinal quantitative dataset was hand collected from a broad range of primary and secondary industry sources. To construct the sample, I relied on a list of all entrants in the industry obtained from i3 – a consulting firm specialized in clean technologies – that was triangulated and expanded using industry reports. I identified and included 249 entrepreneurial ventures developing solar technologies in my sample. Missing data on some ventures led to a final sample of 245 ventures. The variables were coded from press releases, specialized media outlets (e.g. *Photon Magazine, GreentechMedia*) and archival versions of the websites of the ventures (accessed via Archive.org). Each piece of information was triangulated using multiple sources. As the solar PV industry received widespread attention due to public interest in climate change, each venture received great media coverage. This data collection method is in line with methods used in previous industry studies (Benner & Tripsas, 2012; de Figueiredo & Silverman, 2007). The data on venture capital investment rounds into the industry was obtained from *i3* and *VentureXpert*. The data to categorize ventures as industry spinouts was obtained by compiling detailed company histories for each venture in the sample and identifying the prior employment of the founders of each venture.

The quantitative dataset was complemented by qualitative work to familiarize myself with the industry, its technologies and markets. I carried out explorative interviews, read industry reports and specialized magazines covering the industry. The qualitative work enabled me to gain a deep understanding of the different domains in the industry and which functionality attributes they value. It also helped me qualify my results and understand them better.

4.3.4. Measures

Dependent variable

The hypotheses predict the likelihood of choosing a misfit market, i.e. markets in which there is a mismatch between the attributes along which the technology performs well and the attributes valued by customers. To code the dependent variable, I first developed a coding scheme of fit between technologies and markets using the steps that I describe next.

First, based on the qualitative evidence collected, I identified 19 unique markets in the solar PV industry. Combining the 19 markets with the three technological generations in the industry creates a list of 57 technology-market pairs that needed to be categorized. The qualitative evidence is used to identify all the evaluation criteria existing in the industry and to map them onto the 19 markets identified. This allows me to determine which attributes are important in each market for the technology to be considered high performing and to create the coding scheme to categorize the market choices of each venture (See Table 1 and 2 of the Appendix for further details).

Second, I coded each technology-market pair as *low fit*, *partial fit* or *high fit* based on how each technology performs on the attributes considered important in each market. The category *low fit* is used if the technology performs poorly on the attributes valued by the market. Not only does the technology perform poorly on these attributes, but it is also unlikely that the technology can improve its performance on those attributes. For example, the pair silicon-solar glass is coded as having low fit. The market for solar glass highly values transparency and silicon does not offer good performance regarding transparency. Additionally, silicon-based solar cells are unlikely to improve in transparency due to the physical characteristics of silicon as a semiconductor material.

A technology-market pair was coded as *partial fit* when the technology performed well only on some of the attributes valued by the market. Moreover, the technology could improve on the other attributes valued by the market, but another technology was a better fit for that market. For example, second generation thin film technologies based on CIGS are a partial fit for rooftop markets because they offer good performance on costs, one of the attributes valued in this market, but did not perform well on efficiency, even though the technology showed great improvements over time that could help it match this attribute one day. Finally, a technology-market pair was coded as *high fit* when the performance of the technology matched the attributes valued in the market. For example, third-generation technologies are an excellent fit for solar glass because they do extremely well on transparency, offering the opportunity to make transparent solar glass and also colored solar glass.

Third, I used this coding scheme (see Table 4 of the Appendix) to categorize the market choice made by each venture. Market choices are coded from announcements of markets by the ventures. This is an appropriate coding method in the solar PV industry because ventures typically announce markets and unveil a prototype at the same time for that specific market or, when they announce a market with no prototype, they typically follow through and do enter the announced market.

For each market choice made, I checked the level of fit between that market and the technology developed by the specific venture. For example, if a venture developing third-generation solar PV targeted solar glass, the market choice was categorized as high fit. If a venture developing the same technology targeted ground-mounted solar, the choice is coded as low fit.

Lastly, I coded a dummy variable taking a value of 1 when a choice is *low* or *partial fit* and 0 otherwise (*high fit*). The ventures included in the sample (n=245) made 433 market choices. Following the coding scheme, 44.8% of these decisions are categorized as choices with poor fit.

Independent variables

Hypothesis 1 looks at the role of increasing capital availability. To test this hypothesis, I follow prior literature on the role of investment waves on entrepreneurial behavior (Pontikes & Barnett, 2017) and code the variable *capital availability* as the number of VC investment rounds into the industry in the previous period to measure capital availability (i.e. at t-1).

The second hypothesis looks at the role of being an industry spinout. The variable associated with this hypothesis – *industry spinout* – is a dummy variable taking value 1 when the venture's founders were employed in another company in the solar PV industry right before founding the venture of interest (Klepper, 2002 b; Klepper & Sleeper, 2005). In the sample, 25% of the ventures are industry spinouts.

Control variables

I include a number of controls. First, I include two dummy variables to control for whether the market entry decision made by the venture is the first market choice made or a diversification decision. The variable *first choice* takes the value of 1 if this is the first market entry decision taken by the venture. The variable *diversification choice* is equal to 1 if this is a subsequent market entry decision taken by the venture. These variables control for the chance that ventures can make more mistakes the first time they commercialize their technology vs. when they diversify (Gruber et al., 2013).

At the firm level, I include the variable *prior market count* to control for how many markets the venture was pursuing before the choice was made. This is to control for direct knowledge about the demand landscape. In fact, the more markets in which the venture is already commercializing, the more knowledge it has about industry markets and about what is valued there (Gruber et al., 2008; Adner & Levinthal, 2001). I also control for *age* of the venture as ventures have more opportunities to learn about the industry the longer they spend operating in it (Agarwal, Echambadi, Franco & Sarkar, 2004). I also control for the *patent stock* of the venture to control for technical capabilities and product quality that can affect market decisions (Benner & Tripsas, 2012; Furr, 2019). It is possible that ventures make different market decisions once they have raised venture capital (Pahnke, Katila & Eisenhardt, 2015). Therefore, to control for the possibility that ventures enter markets with poor fit because VCs lead them towards larger markets where they can scale up quickly, I include the dummy variable *post VC* taking the value of 1 after the venture has raised its first round of VC.

I control for the stage of technology development using mutually exclusive binary variables for *prototype stage*, *manufacturing stage* and *commercial stage* (excluded category).

These three stages are typical in the solar PV industry. The prototype stage and the manufacturing stage (scale up) require vast amounts of capital. Thus, these variables are included to control for the possibility that ventures choose a market rich in resources to finance these two stages. I also control for two other sources of prior experience of the ventures – ventures with founders from academia or experience in user industries. Experience in academia can influence ventures' strategies and can thus make different product positioning choices than other ventures (Agarwal & Shah 2014). Experience in user industries can affect strategic choices and the ability to understand the demand landscape (Adams, Fontana & Malerba, 2016; Shermon & Moeen, 2020). Thus, I include two binary controls (*user industry*, *academic*) taking the value of 1 if the venture is a user-industry spin-out or an academic venture, respectively. Finally, I control for the technology generation to control for the likelihood that ventures developing more recent generations choose markets that do not value the technology more often because the performance of newer technologies is more uncertain (Furr, 2019). I include two dummy variables, *silicon* and *TF2*, taking the value of 1 if the venture is commercializing a silicon-based technology or a second-generation thin film technology, respectively.

4.3.5. Analytical method and descriptive statistics

The hypotheses are tested using a modification of the Cox model for survival analysis that accounts for multiple events (Allison & Christakis, 2006; Thomas, Eden, Hitt, & Miller, 2007). The semiparametric Cox model does not make assumptions about the baseline hazard function (Cox, 1972; Cox, 2018). This is an appropriate method because I have all entrepreneurial entrants entering the sample at different times and in the sample for multiple years. Furthermore, it allows me to include time-varying covariates in my analysis.

Because market choice events can occur more than once, the use of a modification accounting for multiple events is appropriate (Allison & Christakis, 2006). These methodologies are becoming increasingly established (Furr, 2019; Thomas et al., 2007) to account for time between events and for the lack of independence due to multiple observations for each subject (the entrepreneurial venture in this case).

I run a gap time model that uses the Andersen-Gill variance-covariance matrix (Andersen & Gill, 1982). This model is the predominant correction method used to produce robust estimators (Lin & Wei, 1989) and accounts for time between events by resetting the time after each event rather than measuring time from entry. Table 1 presents descriptive statistics and the correlation matrix for my variables. To address potential concerns about multicollinearity, I calculate the variance inflation factors (VIFs). The average VIF is 1.60 and each value is far from the limit value of 10 (Neter, Kutner, Nachtsheim, & Wasserman, 1996; O'brien, 2007).

Table 4-1 Pairwise correlation in survival data and summary statistics

		Mean	SD	Min	Max
1	Entry with poor fit	0.1	0.3	0	1
2	Capital availability	28.2	21.0	0	65
3	Industry spinout	0.2	0.4	0	1
4	First choice	0.1	0.3	0	1
5	Diversification choice	0.0	0.2	0	1
6	Prior market count	1.4	0.8	0	4
7	Age	6.7	5.2	1	34
8	Patent stock	5.6	15.0	0	147
9	Post VC	0.4	0.5	0	1
10	Prototype stage	0.4	0.5	0	1
11	Manufacturing stage	0.2	0.4	0	1
12	User industry	0.1	0.3	0	1
13	Academic	0.2	0.4	0	1
14	Silicon	0.5	0.5	0	1
15	TF2	0.3	0.5	0	1

n=2,498

Pairwise correlation in survival data and summary statistics (cont.)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Entry with poor fit	1														
2	Capital availability	0.11	1													
3	Industry spinout	0.00	-0.07	1												
4	First choice	0.59	0.11	0.02	1											
5	Diversification choice	0.23	0.03	-0.03	-0.05	1										
6	Prior market count	0.12	-0.08	0.05	0.11	0.24	1									
7	Age	-0.14	-0.23	0.01	-0.33	0.10	0.42	1								
8	Patent stock	-0.02	0.03	-0.08	-0.09	0.14	0.20	0.2	1							
9	Post VC	-0.05	0.15	-0.08	-0.11	0.09	0.06	0.2	0.33	1						
10	Prototype stage	0.16	0.13	0.01	0.33	-0.11	-0.32	-0.5	-0.21	-0.17	1					
11	Manufacturing stage	-0.04	0.02	-0.03	-0.11	0.05	-0.04	0.0	0.02	0.23	-0.43	1				
12	User industry	-0.01	0.04	-0.10	-0.01	-0.02	-0.06	0.0	-0.07	-0.08	0.00	-0.02	1			
13	Academic	0.02	0.02	-0.28	-0.01	0.06	0.06	0.0	0.07	0.21	0.01	0.09	-0.14	1		
14	Silicon	-0.13	-0.08	-0.02	0.02	-0.03	0.09	0.0	-0.12	-0.12	-0.12	-0.11	0.07	-0.14	1	
15	TF2	0.08	0.02	0.09	-0.03	0.0	0.03	0.1	0.13	0.12	0.01	0.08	-0.12	0.08	-0.53	1

n=2,498

4.4. EMPIRICAL RESULTS

Table 2 reports the results from the analyses that test the hypotheses. The results are reported as coefficients rather than as hazard ratios, to make interpretation easier. This means that positive coefficients are associated with a higher likelihood of choosing markets with poor technology-market fit and negative coefficients are associated with a lower likelihood of choosing markets with low fit. Model 1 presents the baseline model including only the control variables. Models 2 and 3 test Hypotheses 1 and 2 respectively.

I first discuss the results from the baseline model (Model 1). The coefficient associated with the dummy variable measuring whether the entry choice was the first one made by the ventures is positive and significant ($p<0.01$), suggesting that ventures are more likely to choose markets with poor fit when they are making their first commercialization choice. Interestingly, the coefficient associated with diversification choices is also positive and significant ($p<0.01$), even though lower than the coefficient associated with first choice. The coefficient associated with age is negative and significant ($p<0.01$) meaning that as ventures spend more time in the industry, they learn about the demand landscape and are less likely to enter markets that do not value their technology. The coefficient associated with the variable *post VC* is negative and significant ($p<0.01$) as well. Unlike my expectations that ventures would make more choices with poor fit after raising VC, this coefficient points to a negative effect of raising venture capital on choosing markets with poor technology-market fit. Finally, the coefficient associated with the variable *silicon* is negative and significant ($p<0.01$), while the coefficient associated with the variable *TF2* is positive and significant ($p<0.01$). These coefficients support the idea that ventures commercializing newer technology generations are more likely to choose markets that do not fit their technology.

Hypothesis 1 suggests that the likelihood of ventures choosing markets with low fit for their technology increases when there is increasing venture capital availability in the industry. The coefficient associated with *capital availability* is positive and significant ($p<0.05$ in Model

2, p<0.01 in Models 3), providing support for Hypothesis 1. To understand the magnitude of the effect of increasing capital availability, I use the technique suggested by Zelner (2009) to model the predicted probability of ventures choosing a market with poor fit for different levels of investment rounds into the industry. For low levels of investment into the industry – one SD below the mean – the predicted probability of choosing a market with poor fit is 10.94%. This probability increases to 12.79% at the mean and to 14.75%% at one SD above the mean, a 4-percentage point increase in the likelihood of choosing markets with poor fit when VC investment is above the mean compared to when VC investment is below the mean.

Hypothesis 2 predicts that industry spinouts can better interpret the demand landscape and, thus, are less likely to be influenced by the "hyped-up" demand landscape and less likely to choose markets with low technology-market fit during times of high capital availability. The coefficient associate with the interaction term in Model 3 is negative and significant (p<0.05), providing initial support for hypothesis 2. I employ the same technique used for the magnitude of the effect of capital availability to graph the predicted probability of entering poorly fitting markets for different levels of capital availability when the venture is an industry spinout and when it is not (Zelner, 2009). The graph of the interaction is presented in figure 1. The x axis shows increasing levels of capital availability. The y axis shows the predicted probability of choosing a poorly fitting market. The graph shows that industry spinouts are less likely to choose markets with low technology-market fit when investment available in the industry is above the mean, supporting hypothesis 2.

Table 4-2 Continuous time event history model of role of capital availability and industry spinouts on choice of markets with poor technology-market fit (DV= Entry with poor tech-market fit=1)

	Model 1	Model 2	Model 3
Capital availability (t-1)		0.013**	0.017**
		(0.034)	(0.011)
Capital availability (t-1)* Industry spinout			-0.020**
			(0.027)
Industry spinout	-0.045	-0.025	0.639*
	(0.783)	(0.879)	(0.071)
First choice	4.537***	4.489***	4.541***
	(0.000)	(0.000)	(0.000)
Diversification choice	2.936***	3.010***	3.122***
	(0.000)	(0.000)	(0.000)
Prior market count	0.014	-0.015	-0.046
	(0.903)	(0.897)	(0.694)
Age	-0.134***	-0.130***	-0.130***
	(0.003)	(0.004)	(0.004)
Patent stock	0.001	0.002	0.002
	(0.828)	(0.713)	(0.741)
Post VC	-0.725***	-0.749***	-0.758***
	(0.000)	(0.000)	(0.000)
Prototype stage	0.074	0.110	0.109
	(0.768)	(0.659)	(0.669)
Manufacturing stage	-0.284	-0.295	-0.277
	(0.258)	(0.234)	(0.254)
User industry	0.409	0.403	0.423
	(0.117)	(0.117)	(0.102)
Academic	-0.245	-0.241	-0.279
	(0.274)	(0.274)	(0.210)
Silicon	-0.508**	-0.498**	-0.471**
	(0.034)	(0.036)	(0.050)
TF2	0.656***	0.642***	0.641***
	(0.001)	(0.001)	(0.001)
Observations	2,498	2,498	2,498
R-squared	0.409	0.410	0.412
Log-Likelihood	-673.9	-672.2	-670.2

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

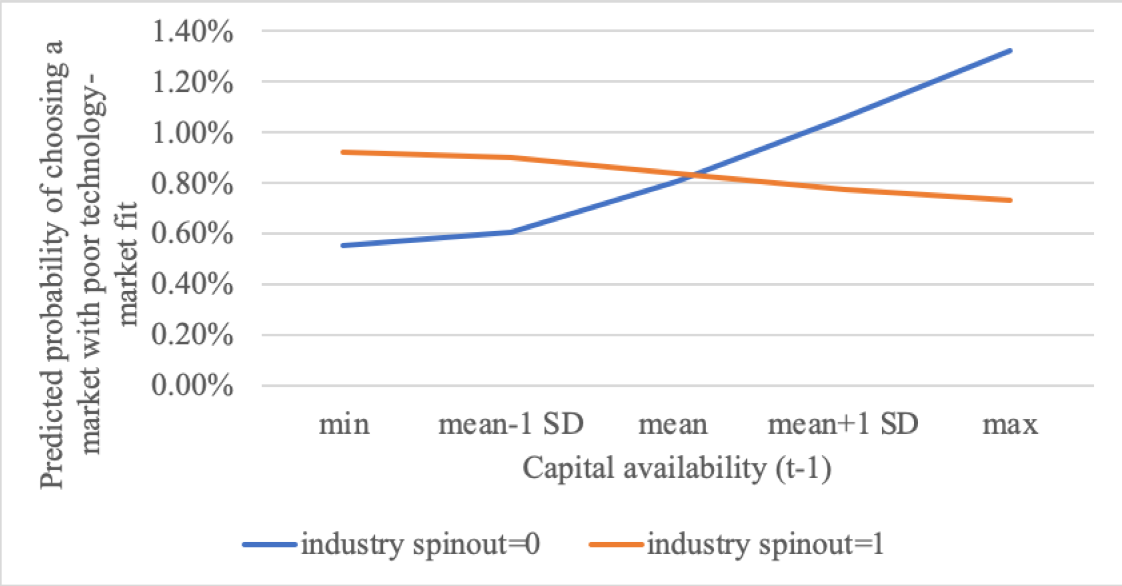


Figure 4-1 Graph the moderating effect of industry spinout on the effect of capital availability

4.4.1. Robustness checks

I test the robustness of the results by performing analyses with alternative model specifications. First, I carry out the same analysis on a more stringent measure of poor fit that includes only the market choice with *low fit* (excluding *partial fit*). In this analysis, 27.5% of the decisions are of poor fit. The results corroborate the ones from the main analysis. Second, the results are robust to using a Logit estimation. Third, the results are robust to a number of alternative specifications of control variables. In detail, they are robust to measuring the cumulative number of VC rounds raised by the venture rather than controlling for whether the venture has raised VC. They are also robust to measuring technology age instream of using dummies for the technology generations and to measuring the number of companies developing the technology rather than the technology generations.

I also performed the analysis including variables that tally the number of VC rounds for windows of two, three and five years. The coefficients are in line with those from the main analysis. I present the results from this specific analysis in Table 3. Panel A presents the results for a two-year window, panel B presents results for a three-year window and panel C present results for a five-year window. Looking at the results of this analysis in particular can shed light on the mechanisms that leads ventures to a misfit market discussed in the first hypothesis. In hypothesis 1, I have argued that capital availability in the previous period creates a "hyped-up" demand landscape that created a widespread cognitive bias. If the explanation that VC investment into the industry in the previous period deteriorates the demand-side information was to be believed, I would expect that ventures are more strongly influenced by the capital invested in the previous period vs. by the capital invested earlier on and for which they can observe the outcomes for the ventures that received the capital.

Comparing the coefficients of the main analysis (Table 2) to the two-year, three-year and five-year windows (Table 3) shows that coefficient become smaller as the time window becomes larger. This suggests that ventures are more influenced by recent capital activity in the industry rather than by observing the outcomes of such activity. This set of results provide support for the suggested mechanism in hypothesis 1 that capital creates a widespread bias at the industry level that leads ventures to choose markets with poor fit.

Table 4-3 Continuous time event history model of role of 2, 3 and 5-year windows of capital availability and industry spinouts on choice of markets with poor technology-market fit
Panel A: 2-year window

	Model 1	Model 2	Model 3
Capital availability (2-year window)		0.007**	0.009***
		(0.025)	(0.009)
Capital availability (2-year window)*Industry spinout			-0.009**
			(0.033)
Industry spinout	-0.047	-0.029	0.610*
	(0.776)	(0.862)	(0.086)
Controls	Yes	Yes	Yes
Observations	2,465	2,465	2,465
R-squared	0.408	0.409	0.411
Log-Likelihood	-672.2	-670.3	-668.5

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Panel B: 3-year window

	Model 1	Model 2	Model 3
Capital availability (3-year window)		0.005**	0.006***
		(0.024)	(0.007)
Capital availability (3-year window)* Industry spinout			-0.007**
			(0.016)
Industry spinout	-0.084	-0.067	0.685*
	(0.616)	(0.691)	(0.055)
Controls	Yes	Yes	Yes
Observations	2,433	2,433	2,433
R-squared	0.418	0.420	0.422
Log-Likelihood	-642.9	-640.9	-638.6

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Panel C: 5-year window

	Model 1	Model 2	Model 3
Capital availability (5-year window)		0.003**	0.004***
		(0.020)	(0.006)
Capital availability (5-year window)*Industry spinout			-0.005**
			(0.018)
Industry spinout	-0.123	-0.105	0.696*
	(0.470)	(0.543)	(0.073)
Controls	Yes	Yes	Yes
Observations	2,368	2,368	2,368
R-squared	0.420	0.422	0.425
Log-Likelihood	-620.1	-617.9	-615.6

Robust p-values in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.4.2. Alternative explanations

The results could be influenced by some alternative explanations. In the next paragraphs, I present some initial evidence that alleviate the concern that these alternative explanations could be driving the results from the main analysis.

The first alternative explanation is that ventures decide to choose markets with poor fit as a strategy rather than as the result of biases. For example, entrepreneurs may have information that have them enter a market with poor fit with the goal of segmenting off a new market. From a qualitative point of view, this alternative explanation seems unlikely in the solar PV context as new markets or uses in this industry emerge around new applications (i.e.

the technology is embedded in a new product form) rather than around using the same application in a new customer group, which would signal segmenting off a new market.

While I cannot directly rule this alternative explanation out quantitatively, I explore the pattern of choices made by ventures over time. If ventures entered a market with poor fit as result of a strategy – rather than as the consequence of a cognitive bias – I would expect that ventures would engage in this strategy consistently over time, thus choosing markets with poor fit over time.

I look at the distribution of first choices and subsequent choices by whether they are of high or poor fit. Table 4 shows these patterns. Panel A shows that 25% of the ventures made multiple market entry choices over time (n=61) and form the sample for this analysis. Panel B shows whether these ventures made first choices and subsequent choices with high or poor fit. The number of ventures that chose markets with poor fit for both their first entry choice and for their subsequent choice is 12, corresponding to 19% of the ventures in the sample for this analysis and 5% of all the ventures. I also see that ventures that chose a poorly fitting market for their first market-entry decision (25 ventures, 40% of this sample, 10% of total ventures) are more likely to choose markets with a better fit when diversifying, in line with the expectation that ventures learn about the industry and its markets. Panel B alerts us to an interesting finding: there are ventures that choose a well-fitting market when they made their first market entry decisions but then chose markets with poor fit when they diversified (n= 15, 24% of sample for this analysis, 6% of total number of ventures). Panel C explores the sample including only the subsequent choices and compares each choice with its previous one (vs. comparing diversification choices to the first market entry choice as in Panel B). The vast majority of choices (206 out of 232) are not of the same type as the previous choice, meaning that high fit choices were preceded by choices with poor fit and vice versa. Once again, the analysis shows that only 4% (n=26) of subsequent choices with poor fit follow another choice with poor fit. We are again alerted to the existence of choices of poor fit that follow choices of good fit.

Table 5 explores the patterns of market entry choices made by ventures that entered multiple markets at the same time (n=96) and then also their subsequent choices (ventures that also made these choices, n=27). First, the vast majority of these ventures made concurrent choices of the same type (n = 82) and only 14 of these ventures entered both markets of high and low fit at the same time (this corresponds to 14.6% of the ventures of this sample and 5.7% of the whole sample included in the main analysis). Second, looking at the ventures that also made subsequent choices (n=27), table 6 presents the same pattern shown in table 5: ventures make different types of choices over time.

Taken together, these results suggest that choices made at the same time are of the same type while choices made over time are rarely of the same type. That is, choices with good fit are followed by choices with poor fit and choices with poor fit are followed by choices with better fit. These results provide some initial evidence that the decision to enter a market with low fit is unlikely to be a strategy implemented by ventures consistently over time. Moreover, they support the idea that factors outside the venture play a role on the choice of markets with poor fit. Finally, the findings that choices of good fit are followed by choices (by the same venture) of poor fit corroborate the idea that ventures become biased by external factors over time.

Table 4-4 Tabular summary of ventures and associated market-entry choices by type (high vs. poor fit)
Panel A: Number of ventures that made subsequent (diversification) market-entry choices and ventures that only made one market-entry choice

Venture level (n=245)					
First choice	**Total**	**Subsequent choice**	**%**	**No subsequent choice**	**%**
High fit	117	24	10%	93	38%
Poor fit	128	37	15%	91	37%
Total	**245**	**61**	**25%**	**184**	**75%**

Panel B: Number of ventures that made subsequent market-entry choices of high vs. poor fit by type of first choice (high vs. poor fit)

Venture level (n=245)				
Ventures with subsequent choices (n= 61)				
First choice	**High Fit**	**%**	**Poor Fit**	**%**
High fit	9	4%	15	6%
Poor fit	25	10%	12	5%
Total	**34**	**14%**	**27**	**11%**

Panel C: Number of subsequent market-entry choices by type (high vs. poor fit) and by previous market-entry choice. Sample does not include first market-entry choices

Subsequent choices level (n=232)					
Previous choice	**High fit**	**%**	**Poor fit**	**%**	**Total**
Different type	100	43%	106	46%	206
Same type	16	7%	10	4%	26
Total	**116**	**50%**	**116**	**50%**	**232**

Table 4-5 Tabular summary of venture that did concurrent market-entry choices categorized by type of concurrent choices and type of subsequence market-entry choices

Venture Level					
Ventures with subsequent choices (n=27)					
	Ventures	**Subsequent high fit**	**%**	**Subsequent poor fit**	**%**
All high fit	51	3	6%	9	18%
All poor fit	31	8	26%	2	6%
Mixed	14	4	29%	1	7%
Total	**96**	**15**	**60%**	**12**	**31%**

Another potential concern is that ventures choose markets with poor fit because these markets are resource-rich and it would be easier to raise resources for technology and venture development in those markets (Pontikes & Barnett, 2017). Thus, entry into markets with poor fit would be driven by seeking resources in a specific market rather than by the mechanism I explained in hypothesis 1 about capital availability in the industry – the deterioration of demand-side information. If misfit market choices were done because ventures are chasing resources rather than because demand-side information deteriorates and they see a "hyped-up" demand landscape, we would expect that resource-rich markets are strongly associated with choices with poor technology-market fit,

I partially control for this alternative explanation by including binary controls for the prototype and manufacturing stage of technology development. These two stages require large amounts of investment, but I find that the coefficients associated with these variables are negative, albeit not significant ($p>0.10$), in the main analysis (See Table 2). I now dive deeper into the yearly data to explore this alternative explanation.

First, I explore the patterns of VC investment into different categories of markets to determine which markets are more resource-rich, i.e. they can be categorized as rich or hot markets. I perform this analysis at the level of four macro[5] categories of markets: rooftop, ground-mounted, building-integrated and integrated products. Most of the financing into the industry went into the rooftop and ground-mounted system markets, which received between 23% and 100% of the financing over the years, with an average of 88%. Much less financing went into BIPV and integrated products, which received at most 47% and on average 22% of the capital available. Thus, I consider rooftop and ground-mounted systems to be the hot markets of the industry, and BIPV and integrated products to be cold markets.

[5] While the main analysis is conducted by identifying 19 markets based on different applications, data on investments into each market is accurately available only at the level of the four macro categories.

Overall, there was more entry into rooftop and ground-mounted markets, which were chosen 279 times vs. 154 entries into BIPV or integrated products markets (see table 6). However, table 6 also shows that a larger proportion of entries into rooftop and ground-mounted markets were of high fit (61% and 60%, respectively), unlike what we would expect if ventures choose markets with poor fit to access capital in the markets with the most resources available. These figures provide some initial evidence that the decision to enter a market with poor fit is not driven by the decision to enter a market that has a vast amount of resources available.

I also examine the correlation between investment into markets and the type of entry (poor vs. high fit). Table 7 shows the correlation between investment into a market and entry into that market of high vs. poor fit. The table shows that, for all markets except ground-mounted systems, more money invested into the market is more positively correlated with entry of high fit than of poor fit.

This analysis provides initial evidence to alleviate the concern that ventures choose markets that do not value their technology because those markets are rich in financial resources, thus providing evidence that excludes this alternative explanation.

Table 4-6 Tabular summary of entries with poor and high fit by market

Fit	Rooftop	%	Ground-mounted	%	BIPV	%	OEM	%
Poor Fit	57	39%	53	40%	44	59%	45	57%
High Fit	91	61%	78	60%	31	41%	34	43%
Total	**148**	**100%**	**131**	**100%**	**75**	**100%**	**79**	**100%**

Table 4-7 Correlation table of investment into markets and entry into those markets by type (poor vs. high fit) in the subsequent year

		1	2	3	4	5	6	7	8	9	10	11	12
1	Investment RT (previous year)	1											
2	Investment GM (previous year)	0.99	1										
3	Investment BIPV (previous year)	0.71	0.76	1									
4	Investment OEM (previous year)	0.88	0.91	0.86	1								
5	Entry RT with poor fit	0.51	0.53	0.42	0.45	1							
6	Entry RT with high fit	0.63	0.63	0.22	0.46	0.68	1						
7	Entry GM with poor fit	0.68	0.68	0.37	0.49	0.82	0.81	1					
8	Entry GM with high fit	0.62	0.60	0.15	0.37	0.62	0.88	0.80	1				
9	Entry BIPV with poor fit	0.68	0.71	0.49	0.65	0.70	0.73	0.81	0.59	1			
10	Entry BIPV with high fit	0.75	0.77	0.66	0.78	0.60	0.49	0.45	0.37	0.59	1		
11	Entry OEM with poor fit	0.62	0.62	0.46	0.50	0.84	0.67	0.83	0.62	0.69	0.47	1	
12	Entry OEM with high fit	0.75	0.80	0.62	0.69	0.40	0.49	0.55	0.51	0.67	0.66	0.38	1

n=38

4.5. DISCUSSION

In this study, I explore the role of increasing capital availability and of being an industry spinout on the likelihood that ventures enter markets with poor technology-market fit, i.e. markets in which the performance of their technology does not match the functionality attributes valued by the market. This question deserves scholarly attention because commercialization in markets with poor fit may prevent not only technology commercialization and venture survival, but also larger outcomes such as industry emergence, wealth creation and societal change (Schumpeter, 1934; Shane, 2004). Despite these well-recognized risks, we still lack a systematic examination of why ventures choose markets with poor fit. I leverage the concept of demand landscape to examine the role of industry-level factors and of their intersection with venture-level factors on the choice of markets with poor technology-market fit. The findings from this study make contributions to the literature on technology commercialization of entrepreneurial ventures, entrepreneurial cognition and venture capital.

I extend the literature on technology commercialization of entrepreneurial ventures by bringing in demand heterogeneity and studying its impact on the technology-to-market linking process. In contrast to existing research (Gruber et al., 2008; 2013; Shane, 2000), I do not focus on the ability to identify multiple potential technology-market pairs, but rather on the ability of ventures to evaluate markets and understand whether there is technology-market fit.

The findings show that the phenomenon of choosing markets with low technology-market fit is pervasive in the solar PV industry. In this empirical context, almost 45% of market entry choices were of poor fit, i.e. had low or partial technology-market fit. Using a more stringent measure of poor fit that includes only technology-market pairs that have low fit shows that still almost 30% of the market entry choices are of poor fit. This is a finding in and of itself for the solar PV industry, which can explain some of the long-term dynamics observed in this empirical context such as long-term struggles to bring technologies to market and a high rate of entrepreneurial failure.

Given the negative consequences associated with choosing the wrong market (Molner et al., 2019; Shane, 2004), the fact that a large proportion of the ventures entered markets with poor technology-market fit raises the question of why ventures would ever make such a choice. Explicitly considering the role of industry-level factors, such as capital availability, that obscure part of the demand landscape shows that entry into the wrong market results from a cognitive bias generated by factors external to the venture that prevent ventures from perceiving the real demand landscape.

The finding that increasing capital availability increases the chances of entering a market with poor technology-market fit shows that booming investment into the industry can create a widespread cognitive bias for all ventures in the industry that are looking for a market in which to commercialize their technology. I have argued that increasing capital availability leads to the creation of a "hyped-up" demand landscape in which information about demand does not equally come through for all market and, as a consequence, does not reflect what is happening in the reality of the demand side of the industry (Adner & Levinthal, 2001; Adner, 2002). As ventures rely on this biased demand landscape to make choices, they enter markets with poor fit even though they believe they are making a highly promising choice.

I also explore the alternative explanation that ventures may choose markets with poor technology-market fit because these markets are rich in resources and thus raising financing could be easier. Evidence from a deep dive into the yearly data shows that increased capital influx in a market is associated with subsequent entry into that market in line with the findings by Pontikes & Barnett (2017). However, the evidence shows that increasing investment into a specific market is more strongly correlated with market entry choices that have a high level of technology-market fit rather than choices with low levels of fit (except for the ground-mounted market). These findings counter the explanation that ventures purposefully choose the wrong market to access resources more easily and provide support for the argument that increasing capital availability in the industry generates a cognitive bias for ventures.

Finally, received wisdom from the literature on technology-market linking has illuminated how larger opportunity sets lead to more positive commercialization outcomes because ventures can commercialize on more markets to create more value (Danneels, 2007; Gruber et al., 2008). The finding that many ventures concurrently enter multiple markets that are all of poor fit or only partially of high fit (i.e. they concurrently enter markets with poor fit and markets with high fit) calls this direct link into question and suggests that the link between larger opportunity sets and positive outcomes may be more complex than previously thought. Despite commercializing on multiple markets, these ventures will face intense challenges on all, or at least some of, the markets they have targeted (Molner et al., 2019). The fact that some ventures concurrently made choice with both high and poor fit raises the question of whether just one market with poor fit could threaten the ability of the venture to commercialize the technology and to survive.

Prior work on the role of entrepreneurial cognition has largely focused on the role of internal factors such as prior experience on the choice of markets (Fern et al., 2012; Grégoire & Shepherd, 2012, Gruber et al, 2008; 2013; Shane, 2000). This study extends the literature by examining the effect of factors external to the ventures on the ability to see certain markets or not and on the ability to evaluate them. The findings show that industry-level factors such as previous investment into the industry have an impact on the cognitive process of technology-market linking through their effect of obscuring parts of the demand landscape.

The role of investment in creating a “hyped-up” demand landscape that makes the cognitive process of technology-market linking more taxing for every venture (Grégoire & Shepherd, 2012) shows that industry-level factors can create a widespread bias affecting every venture in the industry. Thus, I join recent research that has begun to explore how firm's cognition can be affected by factors outside of the firm (Benner & Tripsas, 2012).

The examination of the ability of industry spinouts to better sustain the increased cognitive load created by increasing capital availability also shines lights on the interplay between internal venture's endowments and the external environment in influencing ventures' decision making (Nadkarni & Barr, 2008). Examining both internal and external factors gives a more complete picture of the factors affecting cognitive processes. In fact, cognitive processes - such as the technology-to-market linking – relies on gathering information from the environment and analyzing it. Thus, decisions take place at the intersection. Much of current research on the technology-market linking process and on ventures' decisions in general has explored the effect of one or the other factors. In this respect, I complement existing work by exploring both the role of industry-level factors and the intersection between these factors and ventures' characteristics and knowledge (Nadkarni & Barr, 2008).

The finding that industry spinouts are less likely to choose markets with poor fit during times of high capital availability also contributes to the literature on employee entrepreneurship. Prior work finds that these ventures have a survival advantage compared to other entrepreneurial ventures (Agarwal & Shah, 2014; Klepper, 2002; Klepper & Sleeper, 2005) and explains it in terms of superior capabilities and knowledge (Agarwal et al., 2004; Klepper & Sleeper, 2005; Zahra et al., 2007). In this paper, I extend the knowledge argument to argue that spinouts also have superior cognition and can better withstand increased cognitive loads. Thus, I argue that they also have a cognitive advantage, compared to other ventures, that lead them to choose markets with better fit. While studying the survival outcomes of venture is outside the scope of this study, their superior cognitive ability that lead them to better fitting markets can contribute to the survival advantage of spinouts that has been found by prior work.

Finally, the finding about the effect of venture capital investment on entry into poorly fitting markets raises an interesting question regarding the role of venture capital. Current research on venture capital and entrepreneurship has largely recognized a positive role for venture capital. For example, venture capitalists help to professionalize the firm and help to bring products to market (Hellmann & Puri, 2002). The findings from this study point to what could be called a dark side of venture capital investment. In fact, the more VC rounds are made into the industry, the more ventures are likely to choose a technology-market pair of poor fit.

This finding suggests that VC can have a negative impact at the industry level. On the one hand, VC has a negative effect on non-investee ventures that become biased and enter markets where their technology is not valued. On the other hand, there is also a negative impact for the markets. When entry into markets is done by ventures commercializing technologies that do not satisfy customers, over time these customers may abandon the market condemning it to disappear or even preventing its emergence. Thus, my findings suggest that the positive effect of venture capital at the firm level may need to be requalified to consider the potential for spillover effects at the industry level.

4.5.1. Limitations and future research

Like most studies, this one is not without limitations. First, we need to be careful in terms of generalizability. This study explores the hypothesized relationships only in one industry. Future research can explore these relationships in other contexts to establish their robustness. Studies in other contexts will be particularly beneficial to establish the scale of the phenomenon in terms of how many ventures make market entry choices with poor fit in other empirical contexts.

The results from this study create a few avenues for future research. First, future research could explore more closely the role of venture capital on the investee vs. other firms in the same industry to further understand whether there are spillover effects from VC and how they affect industry dynamics. Second, while studying the consequences of choosing a market with poor fit is outside the boundaries of this chapter, future work could examine the consequences of this choice in terms of ability to appropriate value, introduce new products and survival. Finally, in the context of technological change and industry evolution, future work could explore the role of poorly fitting markets on the performance of ventures during technology emergence and once the dominant design has emerged.

4.6. CONCLUSION

To conclude, this study sheds some light on the second step of the technology-to-market linking process: the evaluation of markets. I underscore the influence of industry-level factors on cognitive processes such as the technology-market linking. The findings on capital availability show that entry into markets with poor fit is the consequence of a widespread cognitive bias that prevents ventures from seeing the demand landscape accurately. The findings on industry spinouts show that being incubated in the industry can counterbalance the effect of booming capital activity. These findings also illuminate a cognitive advantage of industry spinouts, compared to other ventures, that complement existing advantages in terms of capabilities and knowledge.

5. FAILING TO DISRUPT: HOW TECHNOLOGY PIONEERS PREVENTED THIN FILM'S SUCCESS

Abstract

In this study, I explore which factors can prevent an industry from reaching widespread commercialization and how the pre-commercialization strategies of the technology dominant ventures play a crucial role for industry evolution during post-commercialization. Through a qualitative study of thin film solar energy, I find that these ventures cognitively framed thin film differently and employed vastly different strategies – a technology-driven one and a paradigm-driven one. During pre-commercialization, these two strategies addressed different needs of the industry and contributed to reaching the instance of first commercialization in their technology variant. Once in the commercialization phase, the interplay of the dynamics generated by these strategies prevented the industry from reaching commercial sustainability and transitioning to maturity.

5.1. INTRODUCTION

The creation of new industries is considered the hallmark of economic growth and societal change; entrepreneurs have long been considered the driving force behind it (Schumpeter, 1934, Shane, 2004). Yet, the creation and emergence of new industries is far from straightforward.

Catalyzed by triggers such as technological breakthroughs, unmet user needs or grand challenges (Agarwal, Moeen & Shah, 2017), industries undergo long periods of incubation characterized by substantial uncertainty before reaching the first instance of product commercialization, signaling the technical viability of the industry (Agarwal & Bayus, 2002; Golder, Sacham & Mitra, 2009; Moeen & Agarwal, 2017). Ushered into the commercialization phase of the industry (Golder et al., 2009), further uncertainty reduction is needed to reach cost-effective, widespread commercialization which signals transition to industry maturity (Agarwal & Bayus, 2002; Golder & Tellis, 1997).

Extant work has given us an impressive body of knowledge on how industries emerge (Agarwal & Bayus, 2002; Golder & Tellis, 1997) and on the strategies used during the commercialization period by entrepreneurial entrants (Furr, 2019). However, much of existing scholarship on technological change and industry emergence suffers from a success bias as it has largely drawn from cases in which technologies were successfully commercialized and industries emerged (Agarwal & Bayus, 2002; Moeen, Agarwal & Shah, 2020). Moreover, given its longtime focus only on the period after the first instance of commercialization, this line of inquiry has often assumed that entrepreneurial entrants in the industry are a homogeneous group that pursue similar strategies (Bayus & Agarwal, 2007), and it has only recently begun to explore how the decisions taken in the incubation phase can carry consequences for the commercialization phase (Roy, Lampert & Sarkar, 2019, Moeen, 2017).

The gaps identified above motivate this study. Together, they suggest that we need an in-depth study about why industries fail to emerge and how the heterogeneity of ventures' strategies affect industry evolution and this industry outcome. Thus, in this paper I explore the following question: *how do the pre-commercialization strategies of technology dominant ventures affect the evolution of the industry post-commercialization, especially regarding its failure to emerge?*

To answer this question, I carry out a qualitative analysis of the commercialization of thin film solar photovoltaic (PV) in the U.S. I use a micro-historical case design (Hargadon, 2015), which allows me to examine the strategies of the thin film dominant ventures and to study how these strategies affected industry evolution and its failure to emerge. U.S. thin film is an appropriate context to study how heterogeneous ventures strategies influenced the eventual demise of the industry.

Favored by crucial scientific advances in the early 2000, thin film technology developed at the time represented a steep improvement over existing methods for production of solar energy. Given such scientific advances and rising interest in climate change and energy independence, the thin film industry received widespread attention from the media, billions of dollars of investment, both public and private, and regulatory support. Despite the support, thin film failed to reach large-scale commercialization. After some spectacular failures, it entered a phase of retrenchment and lost much of its support and resources.

I find that thin film was dominated by a handful of ventures and that these dominant ventures framed thin film in two contrasting ways. A group of ventures, which I term *technology-driven ventures*, anchored their cognitive frame of thin film on the scientific advances that enabled thin film to compete with the existing technology. Another group of ventures, which I term *paradigm-driven ventures*, anchored their cognitive frame of thin film on the grand challenge of alleviating reliance on fossil fuels and the electricity grid and envisioned thin film as a new solar paradigm. In accordance with their frames, they engaged in vastly different strategies with respect to how they developed thin film and which dimensions of uncertainty they addressed. I find that the existence of these two strategies, while beneficial during the pre-commercialization phase, created conditions during the early commercialization phase that led to an increase in uncertainty, inability to aggregate knowledge and prevented the creation of the industry infrastructure necessary for an industry to reach maturity.

With my study, I contribute to the literature on industry evolution and on entrepreneurial cognition. For industry evolution, I highlight the factors that prevent widespread commercialization and trace them back to ventures' cognition during the early phases of the industry. For the literature on cognition, I show that technological frames play a role not only on venture-level outcomes but also on industry-level outcomes.

5.2. THEORETICAL BACKGROUND

The commercialization of new technologies and emergence of new industries is considered a key path to economic growth and societal change (Schumpeter, 1934). Entrepreneurial action is often regarded as the driving force behind the disruption of existing industries and the rise of new ones (Schumpeter, 1934; Shane, 2004).

Extant work on technology commercialization and industry evolution has given us rich insights into the long process behind going from industry inception to the successful emergence of an industry. Robust stylized facts tell us that industries successfully emerge by transitioning across different milestones that usher the industry to the next phase until large-scale commercialization is reached, signaling that the industry has transitioned to maturity and is commercially sustainable (Agarwal & Bayus, 2002; Golder & Tellis, 1997).

Prior work finds that industries are born from many different types of triggers, ranging from technological breakthroughs to user needs to grand challenges (Agarwal et al., 2017;

Ferraro, Etzion, & Gehman, 2015; Shah & Tripsas, 2007; Roy et al., 2019), and are incubated for decades before reaching the first instance of commercialization (Agarwal & Bayus, 2002; Golder et al., 2009; Moeen & Agarwal, 2017). Once the first instance of commercialization has taken place, the commercialization period begins. Stylized findings show that the commercialization period not only is much shorter than the incubation period but that it has also been shrinking over time (Agarwal & Bayus, 2002). Characterized by activity on the product market and low customer penetration (Agarwal & Bayus, 2002; Gort & Klepper, 1982), this period sees an increase in the interaction between supply and demand factors that leads to sales take-off, widely considered as the milestone that ushers the industry to maturity (Agarwal & Bayus, 2002).

Much of extant work has focused on cases in which industries ultimately achieved widespread commercialization (Agarwal & Bayus, 2002; Benner & Tripsas, 2012; Eggers, 2014; Roy et al., 2019, Moeen, 2017), i.e. they successfully reached sales take-off and maturity. A notable exception is the study by Grodal & O'Mahony (2017) of how competing interests of different communities prevented the successful commercialization of the products envisioned by the National Nanotechnology Initiative for molecular manufacturing.

Within this focus on successful emergence, existing scholarship underscores the key role of uncertainty reduction to help industries transition to maturity (Moeen et al., 2020). Drawing from work in multiple disciplines, Moeen et al. (2020) provide a useful typology of uncertainty dimensions. The technology management literature focuses on the development of different technical designs and reduction of technological uncertainty (Tushman & Anderson, 1986; Utterback & Suárez, 1993). Marketing and technology management scholars underscore the importance of understanding customer preferences to reduce demand uncertainty (Adner & Levinthal, 2001, Golder & Tellis, 1997; Molner, Prabhu & Yadav, 2019). The literature on strategic management is concerned with how complementary assets in the ecosystem need to be configured for successful commercialization, underscoring the role of ecosystem uncertainty (Adner & Kapoor, 2010; 2016). Finally, researchers focusing on the legitimacy of the industry highlight the role of institutional uncertainty (Aldrich & Fiol, 1994, Rao, 2004).

Extant work recognizes that uncertainty reduction may be delayed, and in turn, industry emergence may be delayed or fail altogether (Moeen et al., 2020). Since much of the line of inquiry into industry evolution has focused on cases of successful emergence, we have rich insight into the factors that help industry emergence. However, we know much less about the factors that prevent or significantly delay industries from successfully transitioning to maturity.

Extant work has also highlighted the key role played by entrepreneurial ventures in contributing to uncertainty reduction and in shaping the structure of the industry (Agarwal & Bayus, 2002; Gort & Klepper, 1982). For the most part, entrepreneurial entrants have been analyzed as a homogeneous group pursuing similar strategies (Klepper, 2002 a; Bayus & Agarwal, 2007). However, more recent work in this line of inquiry has begun to question the assumption that entrepreneurial entrants are a homogeneous category. From a capability perspective, founders can gain useful knowledge and capabilities in the environment in which they operated before founding the ventures. Employee entrepreneurship, user entrepreneurship and academic entrepreneurship are, in fact, renowned sources of entrepreneurial variety (Agarwal & Shah, 2014). From a cognitive perspective, entrepreneurial ventures vary markedly in their cognition (Furr, 2019; Zuzul & Tripsas, 2019). When new technologies are introduced, there is significant ambiguity surrounding what they do, how they perform, how they should be used and the value they could offer (Anthony, Nelson & Tripsas, 2016; Benner & Tripsas, 2012). Given the limited understanding about the functionality and performance of the technology (Aldrich & Fiol, 1994; Pinch & Bijker, 1984), entrepreneurs vary in how they frame the technology and the new industry (Kaplan & Tripsas, 2008). The ways in which entrepreneurs make sense of the technology and the opportunity it offers not only address uncertainty and ambiguity surrounding the technology and its potential markets, but they also influence the strategies entrepreneurs decide to pursue, such as how they position their venture in the market and whether they change such positioning over time (Zuzul & Tripsas, 2019). Despite the key role played by cognition in entrepreneurial ventures, research has only recently begun to explore the role of entrepreneurial cognition during industry evolution.

Finally, much of current research has focused on how the strategies of the post-commercialization period affect the industry's transition to maturity. Only recently, research has begun to explore how the choices made during the pre-commercialization period affect the post-commercialization one in terms of capability development, resource reconfiguration strategies or how the dimensions of the post-commercialization dominant design are decided during pre-commercialization (Moeen, 2017; Moeen & Mitchell, 2020; Roy et al., 2019).

Taken together, the previous discussion suggests that extant work lacks an explanation of why industries fail to emerge and of how heterogeneity in the strategies used during the early phases of the industry affect industry evolution, leading the industry to fail. Thus, I explore the following question: *how do the pre-commercialization strategies of technology dominant ventures affect the evolution of the industry post-commercialization, especially regarding its failure to emerge?*

5.3. RESEARCH CONTEXT

To answer this question, I turn to the commercialization of thin film solar PV technologies in the U.S. Solar PV is recognized to have the potential to address the issue of climate change through the generation of renewable energy, and the issue of dependence from foreign fossil fuels such as gas and oil.

The photovoltaic potential of semiconductor materials was first discovered in the 19th century by the French physicist Edmond Becquerel, but this scientific observation sat unused for decades. The potential for commercial applicability of solar PV energy was discovered in 1954 by scientists at Bell Laboratories. Relying on silicon as the semiconductor material, solar energy was prohibitively expensive and reserved for partial use on satellites or demonstrative uses. The demand for solar energy from a commercial standpoint, however, was constrained by high costs and the physical structure of silicon, which limited where it could be deployed (Jones & Bouamane, 2012). In the 70s, the U.S. Department of Energy (DOE) began to fund alternative technologies, namely thin film solar, that could address these limitations and bring solar energy to widespread commercialization. The first laboratory to study such alternatives was created in 1972 at the University of Delaware.

Up until the early 2000s, solar energy was still in its infancy. Existing manufacturing methods could not prove that solar electricity was a reliable alternative to electricity generated using fossil fuels. Scientific breakthroughs in research on semiconductor materials and on nanomaterials enabled the development of a new wave of technologies that could address the limitations preventing the market penetration of solar energy – prohibitively high costs and limited applicability due to silicon's bulky and rigid nature. Thin film solar held the promise of bringing solar energy to the same price of energy generated from fossil fuels. This was a crucial goal as solar power could become self-sustaining and thus a viable option for electricity production only if it reached grid parity with fossil fuel-derived energy. Thus, thin film solar established a new paradigm in solar energy production and was expected to emerge as a new solar industry, often labeled Solar 2.0.

Thin film solar received vast amounts of investment from both private and public sources, and media and regulatory support. From a technical standpoint, thin film solar began approaching the same levels of efficiency of the manufacturing paradigm (based on silicon). Some of the thin film variants reached approximately the same efficiency levels of silicon-based solar PV in 2012 and overtook it in 2015 (Figure 1).

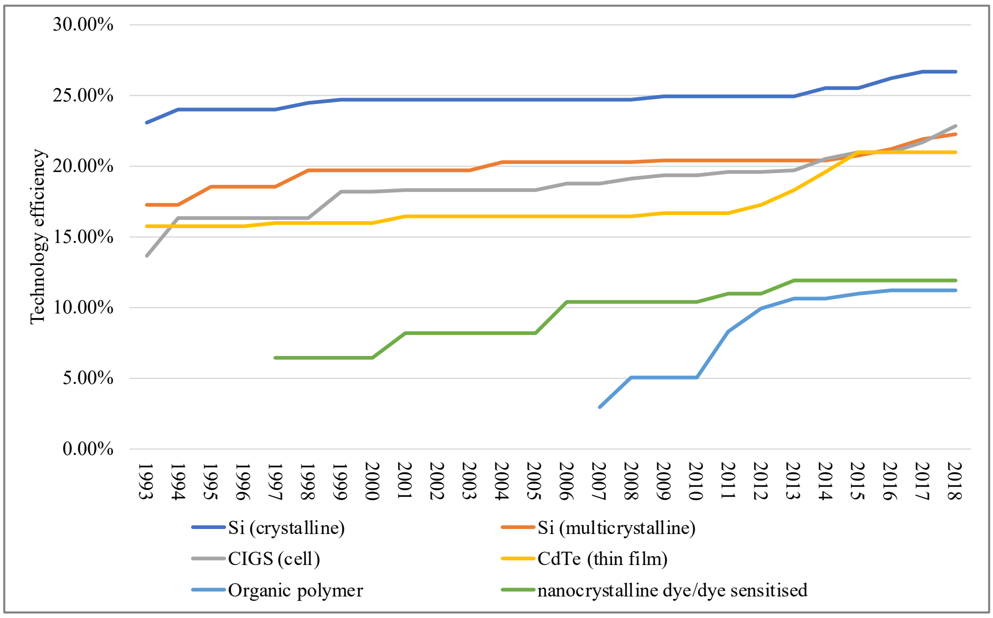


Figure 5-1 Efficiency reached by technology variant over time. Data source: Solar efficiency tables 1-52, Progress in Photovoltaics: Research and Applications, 1993-2018

Yet, despite the widespread support and influx of financial resources and its technical improvements, thin film solar largely failed to deliver; demand never took off and the industry infrastructure did not emerge. As Figure 2 shows, the thin film solar industry reached its peak in 2010 when it generated 16% of solar energy in the U.S. Demand began to drop and reached 10% in 2014 to further decreased to 5% in 2018. Industry participants and observers were aware of the danger in which the thin film industry found itself. In 2012, an article in Recharge, a magazine covering renewable energy news and intelligence, discussed the state of the industry: "*thin-film PV is fighting for its very survival*" (Stromsta, 2012). Over time, thin film solar retrenched and slowly dwindled.

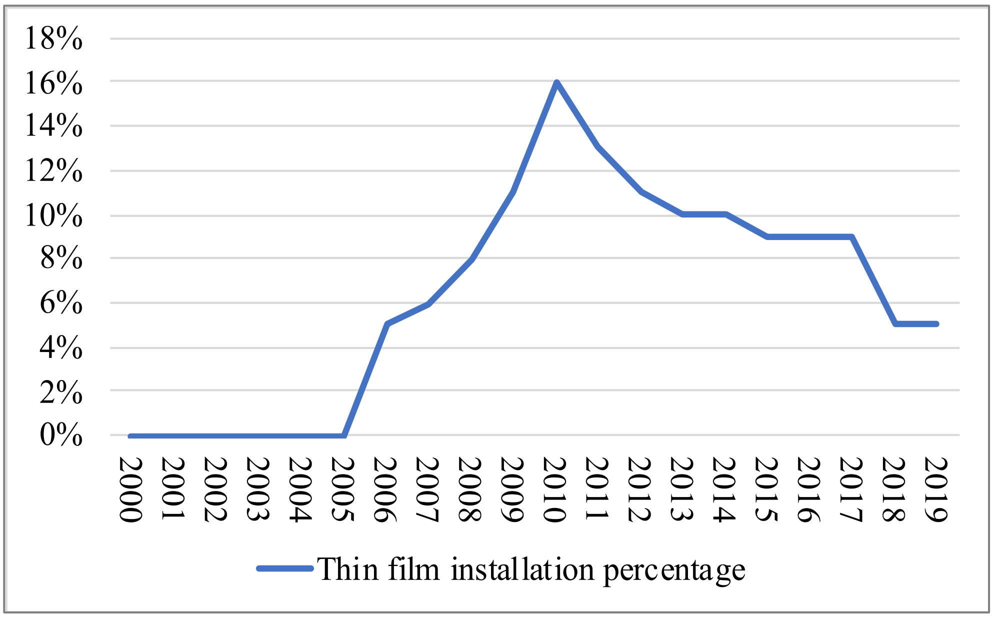


Figure 5-2 Thin film percentage of solar energy, 2000-2018. Data source: SEIA.org

5.4. METHOD AND DATA

To explain how ventures positioned themselves during the emergence of thin film and how their strategy affected their fate, I carry out a qualitative study using the micro-historical case study method (Hargadon, 2015; Hargadon & Douglas, 2001). This method lets me analyze the details of the ventures' strategies and to explore how they related to and shaped the wider industry context. Moreover, due to its reliance on three categories of data sources, this method is particularly useful to understand the interplay between ventures and the industry (Hargadon, 2015). Primary data sources are documents generated by the ventures during the time period under study. They let me understand the strategies implemented by the ventures in the sample. Secondary data sources are materials that are created from primary data sources and provide an interpretation or commentary of primary data sources. They let me glean how stakeholders perceived the actions of the ventures. Tertiary data sources include material that edited primary and secondary data sources, e.g. industry reports, that let me understand how the industry is evolving and how actions from the ventures are affecting it.

The observation window begins in the early 2000s.The sample for this study comprise of nine entrepreneurial ventures commercializing thin film based on of Copper Indium Gallium Selenide (CIGS) and polymers. Focusing on start-ups is appropriate for thin film as most of the ventures that entered the industry were of this type (of 54 total entrants over time, 47 were entrepreneurial ventures). While not the earliest entrants in the thin film industry (Figure 3), these ventures were the dominant players in thin film. In fact, they were responsible for a large proportion of the total installations (measured in megawatt) in thin film (Figure 4). These ventures were widely considered the most influential and most promising ventures in thin film, and industry experts and the media often called them the pioneers of thin film. In fact, their fate was discussed as strongly intertwined with the fate of the industry itself. The ventures included in the sample entered during the pre-commercialization phase of their technology variants and contributed extensively to developing the technology and bringing it to market.

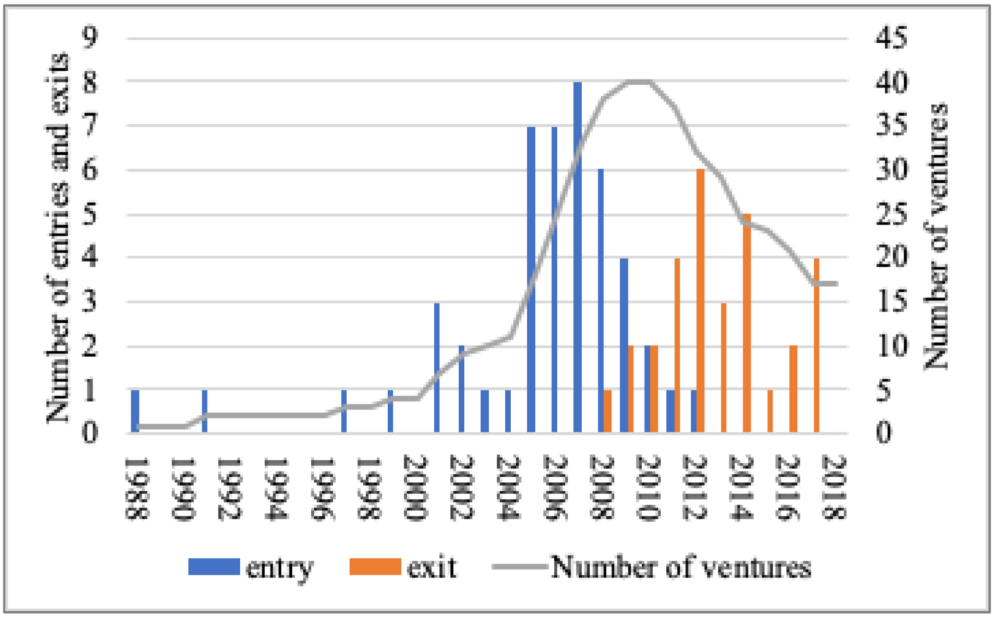


Figure 5-3 Pattern of entry and exit of entrepreneurial ventures in thin film.

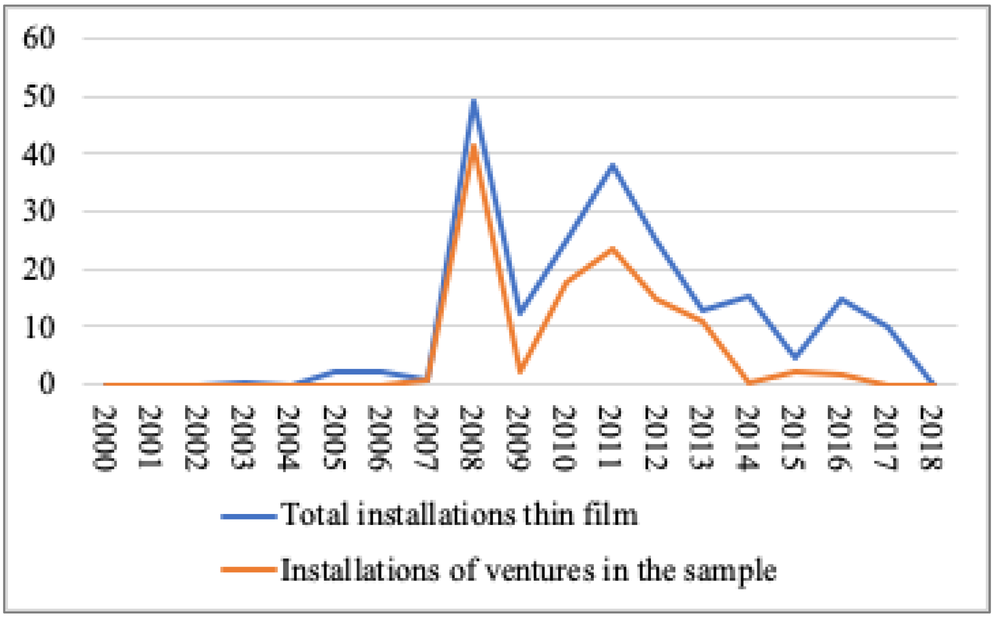


Figure 5-4 Installation of thin film solar (in megawatt – MW) and proportion attributed to the ventures included in the sample of this study

5.4.1. Data sources

I tracked the ventures from their founding until they went bankrupt or were acquired. Ventures that did not exit were followed until 2018. I collected data from a variety of sources and categorized it at the primary, secondary or tertiary level (Hargadon, 2015). Primary data includes press releases (292 totaling 598 pages) of the ventures included in the study, screenshots of their websites and of founders' blogs where they talk about the technology and strategy of the venture (1542 screenshots), and contemporary interviews with CEOs and other members of the venture team (730 quotes). Secondary data includes newspapers and media articles talking about the ventures (403 totaling 871 pages) as well as analysts' and investors' quotes about them, their technology and their strategy (151 quotes). I carried out 6 retrospective interviews to triangulate my findings. The interviewees were entrepreneurs, vice presidents, investors and experts in the industry. The interviews lasted between 30 and 60 minutes and resulted in 25 pages of transcripts. Finally, tertiary data includes newspaper and media article on the industry in general (94 articles totaling 207 pages), reports published by consulting firms and the National Renewable Energy Laboratory (NREL) analyzing the state of the industry and of the technology (7 reports totaling 520 pages) and quotes from analysts and other stakeholders discussing the state and promise of the industry (37 quotes). Table 1 provides an overview of the ventures included in the sample and of the data sources used.

Table 5-1 Overview of the ventures included in the study

	Founding year/Location	Funding	Technology	Outcome	Sources
Nanosolar	2001, Palo Alto, California	$ 527 Mio VC $ 22.09 Mio grants	Nanocrystals/CIGS	Bankrupt in 2013	Primary: 20 PRs totaling 51 pages Secondary: 61 articles totaling 134 pages Primary quotes: 113 Secondary quotes:10 Screenshots: 311
Miasolè	2004, Santa Clara, California	$ 475 Mio VC $ 20 Mio grant from DoE	CIGS	Acquired in 2013 for $30 Mio	Primary: 28 PRs totaling 56 pages Secondary: 38 articles totaling 101 pages Reports: 3 totaling 199 pages Primary quotes: 93 Secondary quotes: 6 Screenshots: 107
Solyndra	2005, Fremont, California	$ 1 Billion VC $ 535 Mio loan guarantee from DoE	CIGS	Bankrupt in 2011	Primary: 35 PRs totaling 69 pages Secondary: 64 articles totaling 116 pages Reports: 1 totaling 25 pages Primary quotes: 43 Secondary quotes: 0 Screenshots: 143
Solopower	2005, San Jose, California	$ 415 Mio VC $ 4.77 Mio grants $ 197 Mio DOE loan guarantee	CIGS	Ceased operations in 2013, restarted in 2015 without production, bankrupt in 2018	Primary: 42 PRs totaling 59 pages Secondary: 73 articles totaling 150 pages Primary quotes: 61 Secondary quotes: 12 Screenshots: 150
Stion	2006, San Jose, California	$ 299.6 Mio VC $ 50.5 Mio grants	CIGS	Bankrupt in 2017	Primary: 39 PRs totaling 65 pages

					Secondary: 38 articles totaling 67 pages Primary quotes: 28 Secondary quotes: 9 Screenshots: 150
Heliovolt	2001, Austin, Texas	$ 207.7 Mio VC $ 1.2 Mio grants	CIGS	Bankrupt in 2014	Primary: 18 PRs totaling 67 pages Secondary: 31 articles totaling 114 pages Primary quotes: 68 Secondary quotes: 18 Screenshots: 138
SIVA Power	2006, Santa Clara, California	$ 137 Mio VC $ 50.65 Mio grants	Nanocrystals/CZTS	Still active at end of study	Primary: 17 PRs totaling 36 pages Secondary: 17 articles totaling 33 pages Primary quotes: 50 Secondary quotes: 1 Screenshots: 50
Konarka	2001, Lowell, Massachusetts	$ 147.3 Mio VC $ 16.23 Mio grants	Nanocrystals/Dye-sensitized	Acquired in 2012	Primary: 69 PRs totaling 132 pages Secondary: 36 articles totaling 94 pages Primary quotes: 25 Secondary quotes: 1 Screenshots: 253
Plextronics	2002, Pittsburgh, Pennsylvania	$ 64.6 Mio VC $ 13.96 Mio grants	Polymers	Acquired in 2014	Primary: 24 PRs totaling 63 pages Secondary: 45 articles totaling 62 pages Primary quotes: 97 Secondary quotes: 27 Screenshots: 240

5.4.2. Data analysis

I coded the data to identify the actions that each venture undertook and how they framed their technology and strategy. I used these facts to create detailed timelines and case histories of each venture (Langley, 1999). The variety and richness of the data sources allowed me to cross-check facts and triangulate information from multiple sources (Jick, 1979). Depending on the venture, the observation period covered 7 to 14 years.

I went through several iterations of reading the data, comparing it to the timelines and case histories, and comparing the ventures' quotes to the tertiary data describing industry dynamics. During this iterative process, I made notes of the emerging theoretical insights and cross-checked them with the case histories to refine my understanding of the context and of the emerging theoretical insights (Danneels, 2007). A first iteration alerted me to the existence of two strategies employed by the dominant ventures. By further comparing between emerging insights and the data, especially secondary and tertiary data, I became aware of how these strategies addressed different dimensions of uncertainty and how they affected the industry. Further analysis helped me explain why the ventures employed different strategies.

5.5. FINDINGS

I find that thin film dominant ventures employed two contrasting strategies. One group of ventures developed a strategy focused on technological development and technical prowess, while another group of ventures pursued a strategy focused on building the new industry. I term the first strategy, *technology-driven strategy*, and the second one, *paradigm-driven strategy*. My analysis suggests that the sharp difference in strategies stemmed from how the ventures framed thin film at entry (Anthony et al., 2016; Benner & Tripsas, 2012; Kaplan & Murray, 2010; Kaplan & Tripsas, 2008), and especially from whether they anchored it to a technical trigger or a grand-challenge trigger (Agarwal et al., 2017). The technology-driven ventures framed thin film as a disruptive technology that would overtake silicon, while the paradigm-driven ones framed it as a new paradigm for energy production. The different cognitive frames led to contrasting strategies that set off dynamics that influenced industry evolution and led to its retrenchment. Table 2 provides a summary of the two strategies and representative quotes.

5.5.1. Technology-driven ventures

Technology-driven ventures anchored the opportunity in the scientific advancements that enabled thin film, i.e. the technological trigger of the industry (Agarwal et al., 2017). As a consequence, these ventures framed the technology in terms of competition with silicon as an attempt to win against the old technology (Christensen, 1997). Accordingly, the features of the technology that they highlighted and focused on for their development efforts were influenced by the old technology, both in terms of what it was not doing well, namely cost, and what it excelled at, namely efficiency. Thus, their technological frame focused on thin film as a way to overtake the old technology, i.e. silicon (Kaplan & Tripsas, 2008). For example, Nanosolar's founder and CEO explained that "*Nanosolar is founded to make a significant difference by developing solar cells with fundamentally better cost/performance*" (Nanosolar.com, 1 June 2001). The founder and CEO of Solyndra addressed the issue directly and stated that he "*sees crystalline silicon panel makers as the company's main competition because their efficiency is much higher.*" (Chernova, 2008).

The way in which technology-driven ventures framed thin film and what it could do directed their strategy. These ventures developed ambitious roadmaps of technology development characterized by well-defined milestones both in terms of scale and timeframe. For example, Miasolè expected to launch production by the end of 2006: "*for $25 million, Miasolè can build a factory capable of churning out 100 megawatts of solar panels a year*" (Kanellos, 2006 b). The technology-driven ventures almost exclusively engaged in individual actions, e.g. actions that furthered the development of their own technology and venture (Lashley & Pollock, 2019). They also showed a marked "do it alone" attitude: they took pride in developing every component of thin film internally – both manufacturing and the semiconductor technology. Moreover, they rarely collaborated for technology development and began collaborating with downstream partners only once the post-commercialization phase began. Nanosolar illustrated the focus on technical uncertainty and the pride in internal development: "*[Nanosolar's] mission is to reinvent the design and manufacturing of photovoltaics to create the lowest cost solar cell and panel. To that end, we persistently pursue innovation and refuse to accept the limitations of existing approaches and practices*." (Nanosolar.com, 30 June 2010). In a similar fashion, Solopower shone light on its "*proprietary and novel electrochemical process*" (Solopower.com, 12 March 2007) and Stion highlighted its "*proprietary materials and device structures*" (Stion PR, 13 September 2011).

To show their technical strength, technology-driven ventures repeatedly released their efficiency records to the public, in most cases before having these records verified for reliability by third parties. In its blog, Nanosolar's founder announced that the venture's R&D team "*managed for the first time to produce solar cells with 14% efficiency"* and underscored that this result was "*a world record for a printed CIGS cell, and, in fact, the most efficient printed solar cell of any kind, ever. Congrats to our science team for this transformational achievement!"* (http://blog.rmartinr.com, 10 May 2006). The founder of Solyndra stated that "*the modules [of the venture] have an efficiency of between 12% and 14%, which is high for thin film, and is "steadily moving up.*" (Chernova, 2008). Miasolè made similar statements 9 times between 2010 and 2012.

Overall, the technology-driven strategy aimed at targeting technological uncertainty (Moeen et al., 2020; Roy et al., 2019). This dimension of uncertainty was the unique focus during pre-commercialization. They addressed other dimensions of uncertainty such as demand or ecosystem uncertainty only during the post-commercialization phase. Thus, they focused on different dimensions sequentially. Within this uncertainty dimension, they tried to redefine solar by developing their own proprietary variant and display their technical capabilities to show progress along their technological roadmap.

5.5.2. Paradigm-driven ventures

Paradigm-driven ventures anchored their view of thin film in the opportunity to develop renewable energy that could contribute to the grand challenge of alleviating climate change (Agarwal et al., 2017; Ferraro et al., 2015). Accordingly, their technology frame revolved around the competition with fossil fuels and the opportunity to become independent of the electricity grid. Thus, they focused their technical efforts on features of thin film that would be beneficial for making solar energy widespread, such as portability, low weight, versatility and flexibility. For example, Heliovolt saw its technological development as "*capable of shifting the world's electricity production focus from one of a fossil-fuel dependent grid-tied model to one that couples production seamlessly with consumption at the site of the building itself*." (Heliovolt.com, 13 October 2006). Similarly, Konarka's CEO stated that they "*want to make portable renewable power practical, affordable and universally available"* and that they wanted "*less consumption of fossil fuels*." (Konarka.com, 13 July 2004).

By anchoring the opportunity within the grand challenge of climate change and framing thin film as competing against fossil fuel, these ventures framed thin film as an emerging industry. Paradigm-driven ventures recognized that building the knowledge necessary for thin film to succeed required the efforts of multiple actors: "*By coordinating our areas of expertise across institutional and country boundaries, we can develop the breakthroughs needed to bring solar power to below €1 Euro per watt, which will open the way for it wide-spread adoption of a new source of power*" (Konarka.com, 24 March 2004).

This perspective influenced their strategy as these ventures attempted to aggregate knowledge from multiple sources and across different dimensions of uncertainty (Moeen et al., 2020). These attempts came in many different forms as the ventures engaged in collaborative individual actions for the benefit of the ventures and also in collective actions that would benefit the industry as a whole (Lashley & Pollock, 2019).

Paradigm-driven ventures collaborated widely with university and industry partners to develop their own technology. They also collaborated with industry actors that could become customers to explore potential markets. NREL was a catalyst for such collaborative efforts. Paradigm-driven ventures collaborated with the lab on many aspects of technological development such as efficiency, manufacturing methods and reliability testing. NREL also supported collaboration through funding with R&D awards. For example, Heliovolt collaborated extensively with NREL to develop its technology. They first engaged in collaborative research with the lab in 2003 and subsequently renewed and expanded their R&D agreement in 2006 and 2010 (Heliovolt PR, 11 November 2003; 11 September 2006; 10 November 2010). Plextronics collaborated both with research institutes such as IMEC (a European independent research institute) to develop its technology (Plextronics.com, 1 September 2008), with research institutes such as the U.S. Army Research Laboratory (Plextronics.com, 25 June 2007) and with industry players such as Acoris Research Ltd to explore potential applications (Indian Business Insight, 2009).

Paradigm-driven ventures also had a "borrow from others" attitude, whereby they used processes and technologies developed elsewhere together with their own technological knowledge. For example, Konarka licensed its technology from a multitude of partners to build on the knowledge developed by these partners. It licensed from universities such as École Polytechnique Fédérale de Lausanne (EPFL) (Konarka PR, 13 August 2002) or Chalmers University of Technology (Konarka.com, 27 April 2004) and from industry players such as DuPont (Konarka.com, 24 February 2004; 22 October 2007). Siva Power discussed its approach to the development of the thin film manufacturing process: "*a key element is using* *glass as a substrate, which has already been scaled in the FPD industry. Much of the necessary equipment is essentially off-the-rack*." (Casey, 2016).

As for their collective actions, e.g. actions that benefit the industry as a whole (Lashley & Pollock, 2019), paradigm-driven ventures lobbied the government to gain regulatory support for solar energy. Plextronics' VP of products spoke at the Subcommittee on Energy and Air Quality on the topic of "*Unlocking America's Energy Resources: Next Generation*." (Plextronics.com, 18 May 2006). The founders and CEO of the paradigm-driven ventures also became part of the leadership of trade associations. For example, the founder of Konarka sat on the board of directors of the Solar Energy Industries Association (SEIA) (Konarka PR, 21 January 2009).

Paradigm-driven ventures also organized consortia and summits to coordinate the actions of multiple actors in the industry. For example, Plextronics co-organized the first "*International Summit on Organic Photovoltaic Stability*" that brought together players from industry, academia and national labs with the purpose of "*instituting a standard for lifetime [of cells] testing* ". Plextronics' CEO argued: "*we are in an emerging and rapidly growing industry, and the best way to maintain the credibility of organic photovoltaics and move the technology forward is to ensure that we are not only sharing information, but also comparing similar results for efficiency achievements, lifetime goals and other important variables*." (Plextronics.com, 2 October 2008). Konarka took part in a consortium of research agencies to "*to overcome crucial obstacles for large-scale production of plastic solar cells*," (Konarka.com, 24 March 2004). Konarka was supposed to "*provide a key role in testing, evaluation, and manufacturing*" (Konarka.com, 24 March 2004).

Overall, paradigm-driven ventures addressed multiple dimensions of uncertainty and did so simultaneously already during pre-commercialization (Moeen et al., 2020). They addressed technical and demand uncertainty by collaborating with others. Technical uncertainty was also addressed by licensing from other actors. Their collective actions aimed at regulatory uncertainty and at establishing a shared and reliable technical knowledge base on which both the ventures and others could successfully build further knowledge.

In the next section, I discuss the specific actions taken by the ventures in different periods and their implications for the ventures and the industry.

Table 5-2 Dimensions of ventures' cognitive frames and strategies and representative quotes

Technology-driven ventures *(Nanosolar, Miasolè, Solyndra, Solopower, Stion)*			
	Dimension	**Theoretical underpinning**	**Representative quotes**
Anchor	Technology	*Technology as the industry trigger (Agarwal et al., 2017)*	
Cognitive frame: Competition	Silicon (the old technology)	*Technological frame is influenced by the old technology and the features highlighted are in function of the old technology (Kaplan & Tripsas, 2008)*	"C*ompared to conventional silicon solar cells, which cost $400 per square meter, Nanosolar's solar cells will cost a tenth as much*" (Nanosolar PR, 19 June 2003). *"The Company's solar cells offer the efficiency of multi-crystalline silicon at a fraction of the cost."* (Miasolè.com, 11May 2004). "*Our mission is to mass-produce photovoltaic (PV) modules for ubiquitous applications on a global scale at a cost lower than the traditional Si technology*" (Solopower.com, 12 March 2007) *"[The] aluminum frames snap together for installation at half the cost and a third of the time of traditional crystalline solar"* (Solyndra's CEO via Ritch, 2008) "*MiaSolé also cites CIGS' three sources of potential cost reductions as being crucial in its competition with silicon-based photovoltaic manufacturers.*" (PV Magazine, 28 October 2011). *"Stion is a leading manufacturer of high-efficiency thin-film solar modules. We are advancing the industry by dramatically improving the cost and performance of solar energy through superior manufacturing and R&D technology"* (Stion.com, 26 Nov. 2012)
Cognitive frame: Technological frame	Focus on features for competition with silicon (cost and efficiency)		
Strategic actions	-Individual actions for venture development -"Do it alone" attitude	*Address technological uncertainty.* *Demand uncertainty addressed only in post-commercialization.*	<u>Individual actions for venture development / "Do it alone" attitude</u> "Our *proprietary technology makes it possible to design and optimize solar cells at the very length scale that the relevant*

	-Ambitious roadmap of technology development with well-defined milestones (scale and timeframe) -Prove technical strength	*Uncertainty dimensions addressed sequentially (Moeen et al., 2020).*	*quantum physics demands it: the nanometer regime*." (Nanosolar.com, 4 April 2004). "*Stion, a next-generation solar photovoltaics company developing high-efficiency thin-film modules comprised of proprietary materials*" (Stion PR, 26 June 2007) Prove technical strength "N*ext generation panel has achieved an aperture area efficiency of 13.4%, a record for flexible copper, indium, gallium and (di)selenide ("CIGS") based modules*." (Solopower.com, 23 March 2012). "*In the crowded field of thin film solar with mostly undifferentiated technology, Stion has distinguished itself with the highest efficiency production ready technology on one square meter, 120 W to 130 W monolithic panels*." (Stion PR, 17 June 2010) "*MiaSolé, the leading manufacturer of copper indium gallium selenide (CIGS) thin-film photovoltaic solar panels, today announced its latest efficiency breakthrough at 13% is now in volume production at its facility in the Silicon Valley, California. This efficiency gain represents a 30 percent improvement since the beginning of the year, while over the same timeframe decreasing costs per watt by a similar amount*." (Miasolè PR, 24 October 2011)
Paradigm-driven ventures *(Heliovolt, Siva Power, Konarka; Plextronics)*			
	Dimension	**Theoretical underpinning**	**Representative quotes**
Anchor	Grand challenge of climate change	*Grand challenge as the industry trigger (Agarwal et al., 2017)*	
Cognitive frame:	Fossil fuels and the electricity grid	*Technological frame around what the technology could do*	"*Our goal is to eliminate the need to plug in any device for a recharge. To do this, we are delivering materials that convert any*

Competition		*ignored the role of the old technology. The features were in function of the market-based vision (Kaplan & Tripsas, 2008)*	*kind of light – outdoor, indoor, low – into energy, enabling consumers to break away from the power grid and reduce their reliance on fossil fuels*." (Konarka.com, 23 August 2004). *"Polymer solar cells will be thin, light-weight products that can even be flexible and portable."* (Plextronics PR, 18 May 2006) "*These lower cost paths to high quality photovoltaic products enable a fundamental shift in our electricity mix from traditional, polluting sources to renewable energy harnessed from the sun*" (Heliovolt.com, 23 October 2008) "We want to *advance America's widespread adoption of solar energy -- what we refer to as Solar 2.0*" (Siva PR, 27 March 2013).
Cognitive frame: Technological frame	Focus on features for vision of solar everywhere (portability, flexibility; versatility)		
Strategic actions	-Individual collaborative actions for venture development -"Borrow from others" attitude -Collective actions for industry development	*Address demand uncertainty already during pre-commercialization.* *Address uncertainty along different dimensions at the same time (Moeen et al., 2020).*	<u>Individual collaborative actions for venture development</u> *Under a $100,000, six-month cooperative r&d agreement with NREL, the company is using the lab's facilities and resources in working to prove the soundness of its patented technology for making thin-film solar cells made from copper indium gallium diselenide (CIGS) films. HelioVolt is providing $75,000 in this phase of the CRADA, with the lab chipping in the balance.* (Inside Energy, November 2003) "*Our collaborative efforts with NREL over the years have formed the groundwork for a viable new solar paradigm: large scale production of building materials that are durable, versatile, visually appealing and capable of economically harvesting energy from the sun,"* (Heliovolt PR, 11 September 2006) <u>"Borrow from others" attitude</u> *"This significant licensing agreement broadens Konarka's technology platform and uniquely positions the Company to take*

			advantage of nanotechnology developments in both dye-sensitized cells and polymer cells," (Konarka.com, 24 February 2004) <u>Collective actions for industry development</u> *"The goal of the MOLYCELL project is to overcome crucial obstacles for large-scale production of plastic solar cells. By bringing together Europe's best scientists and business leaders in the field of solar technology, the program will focus on developing and manufacturing a new generation of organic photovoltaic materials having better efficiency, longer lifetime and a production cost far below those of competing technologies based on silicon," (*Konarka.com, 24 March 2004) *"We will overcome a long identified obstacle to widespread adoption of solar electricity – the lack of standardized low cost manufacturing systems for thin film compound semiconductors*" (Heliovolt.com, 20 July 2004) *"Plextronics, Inc. and Coatema hosted a masterclass as part of the Printed Electronics Europe tradeshow being held this week in Dusseldorf, Germany. The class, "Thin Film Photovoltaics: Principles, Technologies, Markets," was held on Monday, April 4 from 8:30 a.m. to 1:00 p.m. at Coatema's facility in Dormagen, Germany." (*Plextronics.com, 21 April 2011*)* *SIVA Power hired Jim Woolsey in 2013 to advocate for renewable energy: "Jim Woolsey is a wise and experienced hand on the government side of things, and a tireless advocate for viable clean technologies. He fully grasps the benefit of distributed solar as America's best solution for both energy independence and energy security."* (SIVA Power PR, 27 March 2013)

5.5.3. Entrepreneurial strategies and industry evolution

I tracked the two strategies identified over three phases: (1) a pre-commercialization phase (2000-2007), (2) an early commercialization phase (2007-2011) and (3) a retrenchment phase (2011-2016). The analysis shows that the two strategies had different outcomes for the ventures and also had implications for the evolution of the thin film solar industry.

5.5.3.1. Phase 1: pre-commercialization (2000-2007)

During the pre-commercialization phase of CIGS and polymers, there was still widespread uncertainty regarding whether thin film could reach the market. The major source of uncertainty was technological development and the key questions were about which specific variant would work, whether the manufacturing process could be developed and scaled (Tushman & Anderson, 1986; Utterback & Suárez, 1993) and whether thin film could deliver in terms of efficiency. At the same time, the industry needed to gain institutional support and resources to enable ventures to develop the technology (Aldrich & Fiol, 1994, Rao, 2004).

Venture-level strategies and outcomes

The technology-driven ventures invested heavily in addressing technical development of their technology variant. They pursued aggressive technological roadmaps with well-defined milestones in terms of scale and timeframe. As they envisioned their technology in terms of competition with silicon, their roadmaps focused on efficiency and cost.

As highlighted in the previous section, they developed a "do it yourself" attitude with respect to technological development. Even university spinouts such as Stion focused on developing every component they needed in-house after licensing the original technology from their university. These ventures engaged in little collaboration for research purposes and took pride in their ability to develop the technology, the manufacturing process and the necessary equipment in-house, which they often discussed as proof of their technical strength.

This strategy played out well for them. Their focus on taking over the old technology (Adner & Kapoor, 2016) and establishing themselves as the technical reference in the field revealed attractive for venture capitalists who began investing heavily in these ventures. The first high-profile deal in the industry was, in fact, Nanosolar in 2002. The company announced: "*Nanosolar closes its series A financing and becomes the first solar-cell company to receive blue-chip Sand-Hill-Road venture-capital backing*." (Nanosolar.com, 1 December 2002). Investors stressed that they were attracted by these ventures because of their potential for good returns, rather than because they were interested in the potential of solar energy to alleviate climate change. As Arno Penzias, partners at NEA, stated, "*VCs are attracted to solar power technology because it is more scalable than other areas of alternative energy*." (Sheahan, 2005). Similarly, Ira Ehrenpreis, a venture capitalist with Technology Partners, stated that *"The reason we're allocating dollars to this sector is we think we can deliver attractive returns. It's not because we want to do great things for the environment or great things for the world, […] though that is a "great byproduct.""* (Rivlin, 2005). At the same time, their framing around competition with silicon, and especially their vivid accounts of beating silicon, was also picked up by the media. Over time, the media began to use this framing around overtaking silicon to describe the whole emerging thin film industry (Martens, Jennings & Jennings, 2007; Lounsbury & Glynn, 2001): "*The booming solar industry is in the midst of an argument over which material will become dominant in the future for harvesting sunlight and turning it into electricity*" (Kanellos , 2006 a).

The paradigm-driven strategy starkly differed. In light of their goal to create a new paradigm for energy production, paradigm-driven ventures addressed multiple sources of uncertainty at the same time and attempted to create a reliable knowledge base. Recognizing that they did not possess all the knowledge to develop the industry, they collaborated for both research and market exploration purposes. They also developed a "borrow from others" attitude, which translated into using standardized equipment, adapting processes from technologically-related industries such as the glass industry, and also licensing technology from universities and other firms over time. Finally, they took part in collective actions such as the organization of consortia addressing specific technological issues to aggregate knowledge and define common grounds for the industry to move forward. They also lobbied the government for support for solar energy.

Their framing and strategy that highlighted the importance of collaboration matched the requirements for raising public money via grants (Pahnke, Katila & Eisenhardt, 2015). In fact, these ventures were very successful at raising numerous grants from NREL, DOE and also state-level grants. During the pre-commercialization period, these ventures raised public money in 22 instances. In contrast, they were not as successful in raising financing from venture capitalists and they started raising VC later than technology-driven ventures. The first VC round into one of these companies was in 2004 when Konarka raised $18 Millions from a syndicate of investors including New Enterprise Associates and Vanguard Ventures (Konarka.com, 23 June 2004). They also raised smaller rounds at lower valuations. Of one investment round into Konarka, industry analysts said, "*The valuation is markedly lower than some of the deals signed by thin-film solar technology developers in 2008, like Nanosolar and Miasolè, which were valued at above $1 billion each*." (Chernova, 2008 b). Their ability to raise VC picked up towards the end of the pre-commercialization period. Their framing was also not picked up extensively by the media. Their narratives were not as vivid despite the focus on overthrowing the current way of producing electricity (Martens et al., 2007).

Overall, the strategy employed by the technology-driven ventures proved extremely successful during the pre-commercialization phase. Their framing around technological change and replacing another technology that seemed to have reached maturity (Adner & Kapoor, 2016) matched the requirements of venture capitalists for scale (Pahnke et al., 2015). Moreover, their roadmaps that envisioned this change within short years also matched the VCs' requirements for high returns within a specific window (Pahnke et al., 2015). This match enabled them to raise significant capital early on at high valuations from prominent VC firms. In contrast, paradigm-driven ventures lacked the ambitious and well-defined technology roadmaps that would match the requirements of VCs for scale and high-returns within a specific timeframe (Pahnke et al., 2015). Their focus on creating a new paradigm for energy production, on decreasing reliance on fossil fuels and on positive changes for the environment was considered an afterthought by VCs – a *"great byproduct."* (Rivlin, 2005) but nothing more. As such, their ability to raise VCs was much inferior to technology-driven ventures.

On the contrary, given the match with the logics of public money providers (Pahnke et al., 2015), they were more successful at raising money via grants. During pre-commercialization, they won 22 grants vs. 13 grants won by technology-driven ventures.

The two strategies also had different outcomes in terms of success of their cognitive frame. For technology-driven ventures, the vividness of their cognitive frame and the way in which they pictured it in their narratives piqued the interest of the media that made their frame the prominent one in the industry, largely disregarding the potential for independence from fossil fuels (Martens, et al., 2007; Lounsbury & Glynn, 2001). The paradigm-driven ventures were also comparatively less successful in disseminating their cognitive frame of thin film. Much less vivid narratives prevented their frame from raising the interest of the media and remained a secondary frame during pre-commercialization.

Industry-level dynamics and outcomes

At the industry level, the strategies implemented by the ventures during the pre-commercialization phase revealed successful and contributed to uncertainty resolution (Moeen et al., 2020). The hallmark of uncertainty resolution was the commercialization of the first thin film cell based on these innovative technologies in September 2007 by Miasolè (Chernova, 2007) and Nanosolar a short few months after (http://blog.rmartinr.com, 18 December 2007). Plextronics and Konarka managed to commercialize and ship the first cells based on their technological variant about a year later (Plextronics.com, 10 June 2008; Konarka.com, 20 August 2008). The first commercialization heralded the transition to the phase of early commercialization (Phase 2 – 2007 to 2011).

At the industry level, the key factors that enabled the successful transition from pre-commercialization to early commercialization were the match between industry needs and entrepreneurial strategies and the complementarity of the two strategies in addressing dimensions of uncertainty. The key industry needs during this phase were resolution of technical and demand uncertainty to bring the technology to market and the need for resources to develop the technology (Moeen et al., 2020).

Both groups of ventures invested significant time and resources in the resolution of technical uncertainty (Roy et al., 2019; Tushman & Anderson, 1986; Utterback & Suárez, 1993), despite attacking the issue in fundamentally different ways. Technology-driven ventures focused on the attributes of cost and efficiency. Since the ability of thin film to perform in terms of efficiency was a crucial source of uncertainty during pre-commercialization, the technical development of these ventures helped address and resolve this key question. Whether thin film could successfully be manufactured was another key question. Paradigm-driven ventures addressed this issue with their collaborations and by adapting proven manufacturing methods and equipment from other industries. Paradigm-driven ventures' collaborations with potential customers were also critical to addressing demand uncertainty and develop demand for the industry (Agarwal & Bayus, 2002; Adner & Levinthal, 2001; Molner, et al., 2019).

Both strategies also contributed to attracting attention and resources to the industry, yet in different ways. The technology-driven ventures piqued the interest and attention of the media and the general public due to their skilled narratives (Martens et al., 2007; Lounsbury & Glynn, 2001). As a consequence, they managed to legitimize the industry in the eyes of the general public on the premise that thin film was going to be the next revolutionary technology.

Paradigm-driven ventures gained the support of the government through their lobbying and helped create a favorable regulatory environment for the industry. Thus, the two strategies helped legitimize the industry in the eyes of different stakeholders (Fisher, Kuratko, Bloodgood & Hornsby, 2017).

Technology-driven and paradigm-driven ventures also brought resources to the industry from different stakeholders. Technology-driven ventures attracted significant amounts of venture capital and further legitimized the industry because they attracted the interest of prominent venture capitalists, a signal of quality not only for the venture (Stuart, Hoang & Hybels, 1999) but also for the industry since highly reputable venture capitalists are often the first ones to invest in emerging industries (Petkova, Wadhwa, Yao & Jain, 2014). By kickstarting the investment of venture capitalists, they attracted a type of financing that is considered key for the development of high-tech industries. In contrast, paradigm-driven ventures attracted public financing that was crucial for sustaining private-public collaborations.

It is important to note that during pre-commercialization, there was little interaction between the two strategies and that the two largely developed along their own trajectories. While paradigm-driven ventures engaged in collaboration with different industry actors, they rarely tried to engage in collaboration with technology-driven ventures. Thus, the collaborative efforts took place within the strategy rather than across strategies. Furthermore, the two strategies contributed to resolving different aspects of uncertainty as pointed out in the previous paragraphs. On the one hand, technology-driven ventures focused on technical development for cost and efficiency, gained the favors of the media and public and financial resources from VCs. On the other hand, paradigm driven ventures, focused on technical development for portability and reliability, gained regulatory support and financial resources in the form of research grants. By addressing different facets of uncertainty, these two strategies were complementary in addressing the industry needs and they jointly contributed to uncertainty resolution and helped the industry reach commercialization (Moeen et al., 2020).

5.5.3.2. Phase 2: early commercialization (2007-2011)

Once in the early-commercialization phase, the key issue of whether thin film could reach the market was resolved. Accordingly, the sources of uncertainty in the industry shifted. From a technical standpoint, efficiency lost importance over time as a critical issue to address as some thin film variants approached silicon's efficiency (see Figure 1). Reliability and lifetime became crucial pain points that needed to be addressed to prove that thin film could succeed in commercial applications. The issues of reliability and lifetime were also critical for the demand dimension as they were vitally important to increase adoption and market penetration (Agarwal & Bayus, 2002; Gort & Klepper, 1982). Widespread adoption also hinged on the ability to understand customer preferences with respect to which performance attribute was cared about by customers in different sub-markets (Adner & Levinthal, 2001). The need to develop an industry infrastructure that could support cost-effective scaling also gained importance (Adner & Kapoor, 2010; 2016).

Despite the many sources of uncertainty left within the dimensions of technological demand and ecosystem uncertainty (Moeen et al., 2020), the future of the thin film solar industry seemed promising. A report by GreenTech Media forecasted "*thin-film production to double in each of the next three years, with CIGS being the most "exciting yet elusive*." (GreenTech Media, 2008).

Venture-level strategies and outcomes

Both technology-driven and paradigm-driven ventures largely stuck to the same strategies they had employed during pre-commercialization with limited changes that would address the new concerns of the early commercialization phase.

Technology-driven ventures maintained their focus on individual actions (Lashley & Pollock, 2019) that addressed their own technical and venture development. For technical development, they maintained their "do it yourself" attitude and, in accordance to their framing of technological competition with silicon, they kept focusing on efficiency and cost as the key attributes to develop.

The changes to their strategy revolved around reducing demand uncertainty. Technology-driven ventures began addressing demand uncertainty by showcasing their cells at industry events and conferences. For example, Solyndra began attending conferences and showcased its cells starting at Solar Power International in October 2008 (Ferenbacher, 2008). Solopower showcased its technology at the same industry event a year later (Solopower.com, 26 October 2009). The ventures also regularly attended Intersolar, another major industry conference. Technology-driven ventures also began to collaborate with distributors to bring their technology to market. Yet, in contrast to the co-development and market exploration strategy pursued by paradigm-driven ventures during pre-commercialization, they preferred contractual agreements to support sales. For example, Miasolè established more than ten partnerships with distributors between the end of 2009 and 2012; Solyndra established more than 20 such partnership between mid-2008 and 2010.

At the venture level, the strategy they set up during pre-commercialization began to backfire. Technology-driven ventures had foreseen an aggressive move down the technological curve with highly specific milestones. This strategy enabled them to raise much needed resources during pre-commercialization but also gave investors and the public a way to precisely measure their progress. When these ventures began to clearly miss their aggressive milestones of cost reduction and manufacturing ramp up, stakeholders began to raise questions.

At the same time, technology-driven ventures began to announce record-breaking efficiency measurements that were meant to showcase their technological progress. Such announcements were often given before independent testing of the efficiency by a third party such as NREL. These uncertified efficiency records coupled with missed milestones on every other aspects of technical development led investors and the public to question the ventures' abilities to deliver on their promises and the overall ability of thin film to progress. The general media highlighted that "*mass production [of thin film] is an entirely different story. Many of the CIGS start-ups have had trouble producing high-efficiency cells on a commercial scale. Last year, Miasolè delayed releasing its solar cells because the products coming off the line were generally exhibiting 4 to 6 percent efficiency, below the company's 8 to 10 percent target*." (Kanellos, 2008). Paul Maycock, president of the solar consulting and electric firm Photovoltaic Energy System, commented on GreenTech Media that "*It's very easy to set goals. But the proof will be in the eating*." (Barron, 2008). In 2010, the media started to openly criticize these ventures' strategies and lack of achievements: "*One of the more bombastic of the Cigs boosters, the Santa Clara, Calif. company Miasolé, said in September 2006 it expected $100 million in sales by the end of 2007. That year passed without any revenue. As did 2008 and the first three quarters of 2009*" (Fahey, 2010). The same article also noted that "*Not a single Cigs company hit its target. Less than 1% of the installed solar photovoltaic capacity in the world is based on Cigs.*" (Fahey, 2010).

At the venture level, the missed milestones, coupled with a tough post-financial crisis environment, led to increasing difficulties in raising the additional financing needed to further develop and scale up. In fact, many investors pulled out and these ventures raised fewer rounds. Venture capitalists were markedly less interested in funding solar ventures: Michael Goguen of Sequoia Capital ventured to say that the search for financing of these ventures was "*pretty hopeless*" (Groom, 2011). Nanosolar was only able to raise two rounds of $20 and $70 Millions, respectively, after 2008 compared to its previous six rounds amounting to $476.5 Millions. Similarly, Miasolè raised two rounds totaling $150 Million compared to $325 Millions raised previously in seven rounds. Solopower managed to raise only one round during the early commercialization phase (in 2008), as did Stion (in 2010).

Similar to technology-driven ventures, paradigm-driven ventures also mostly pursued the same strategic actions that they used during pre-commercialization. They still engaged in collaboration with academia and industry players to further develop the technology and to understand how to deliver a technology that would satisfy customers' preferences.

What changed during the early commercialization phase was the focus of their collaborative technical development. They increasingly focused on determining ways to show whether results were reliable and could be used for further research. This took the form of relying on third-party independent testing of their efficiency measurements, having their cells deployed at the NREL testing site or having their own testing site. Konarka had the lifetime of its solar cells already tested in 2008 by the Energy Research Centre of the Netherlands (ECN) (Penton Insight, 2008). Plextronics had its cells tested by NREL in 2007 and then again in 2009 (Plextronics.com, 9 August 2007; 17 August 2009). In 2008, Heliovolt released its efficiency measurement only after they had been certified by NREL (Heliovolt PR, 12 May 2008).

Reliability of measurements was addressed also via collective actions. In October 2008, Plextronics co-hosted with the DOE and NREL the first International Summit on Organic Photovoltaic Stability (Plextronics.com, 2 October 2008). The summit gathered leaders from industry, academia and national research institutions to discuss issues related to stability and general measurement practices. The goal was to create a set of accepted procedures to quantify degradation. In a sense, the participants wanted to create a "language" that could be understood by all organizations in the industry and facilitate comparisons. The CEO of Plextronics commented that developing standards for testing was vital for commercialization and that widespread partnering among different organizations was key to making it happen. He added that "*We are in an emerging and rapidly growing industry, and the best way to maintain the* *credibility of organic photovoltaics and move the technology forward is to ensure that we are not only sharing information, but also comparing similar results for efficiency achievements, lifetime goals and other important variables*." (Plextronics.com, 2 October 2008).

All in all, the strategies developed by paradigm-driven ventures during the pre-commercialization phase helped them during the early commercialization phase as well. First, their collaborations with universities and national research institutes helped them gather financial resources via public grants even during the difficult financial climate present in 2008 and 2009. Moreover, these collaborations made them more receptive to the increasing importance of third-party testing to ensure that existing knowledge could be reliably built upon. Second, their roadmaps had been far less reliant on milestones detailed in scale and timeframe. Despite suffering the same delays in development as technology-driven ventures, they were able to weather such delays receiving far less criticism.

Overall, the strategy that made technology-driven ventures wildly successful during the pre-commercialization phase was also the source of their struggles during the early commercialization phase. The inability to deliver on their promises of a speedy breakthrough drove investors away and was detrimental to their ability to raise further financing. While the economic downturn obviously played a role in creating a tougher environment in which to raise financing, the strategy they employed in the pre-commercialization phase contributed heavily to their inability to gather further financial resources. In fact, paradigm-driven ventures that had started to rely on financing from venture capitalists later than technology-driven ventures and that also relied heavily on public grants in virtue of their willingness to collaborate suffered less from the tougher financial environment and were able to keep raising financial resources via R&D grants.

At the venture level, the paradigm-driven strategy turned out to be more successful in the early commercialization phase compared to its limited success during pre-commercialization. On the contrary, the success of the technology-driven strategy during pre-commercialization was not sustained once thin film was on the market.

Industry-level dynamics and outcomes

At the industry level, the strategies implemented by these dominant ventures set dynamics in motion that over time prevented thin film from scaling up and reaching widespread commercialization. The early commercialization phase of thin film ended with the bankruptcy of Solyndra in 2011. Solyndra's bankruptcy was a watershed moment in the thin film industry, which precipitated a change in public opinion regarding the promise of thin film and stigmatized the industry.

Instead of further uncertainty reduction that would have led to increase in demand (Agarwal & Bayus, 2002, Gort & Klepper, 1982) and to entry of new firms that would have created the industry infrastructure for cost-effective scale up (Adner & Kapoor, 2010), the early commercialization of thin film witnessed a slowdown of uncertainty reduction. The strategies of the thin film dominant ventures – largely considered the most important players in the fledging industry – prevented further uncertainty reduction. The inability to further resolve uncertainty to the point of enabling mass production and widespread commercialization, i.e. sales take off (Agarwal & Bayus, 2002, Gort & Klepper, 1982) can be traced back to two factors. First, the mismatch between strategies and the sources of uncertainty in the industry. Second, the questioning of the existing knowledge base.

The mismatch between sources of uncertainty and what the strategies of technology-driven and paradigm-driven ventures were addressing limited uncertainty reduction. From the technical standpoint, the success obtained during pre-commercialization by technology-driven ventures entrenched their cognition and they maintained their focus on efficiency and cost as the main pain points to address. During the early commercialization phase, efficiency levels reached by thin film slowly increased and the importance of efficiency as a critical uncertainty decreased. As for cost, a decrease in the cost of silicon due to the extension of the silicon value chain (Adner & Kapoor, 2016) made it increasingly difficult to justify cost as the selling point for thin film and as the crucial functionality to address (Adner & Levinthal, 2001). Despite the changes in what constituted the critical technical uncertainties that needed to be addressed – decreasing importance of cost and efficiency and increasing importance of reliability and lifetime – technology-driven ventures took years before addressing the new constraints.

Paradigm-driven ventures, for their part, began addressing the new sources of technical uncertainty in a timelier manner, possibly due to their collaboration with national research institutions. Yet, they too failed to address the needs of the industry completely. In their case, the strategic mismatch was on the demand side. In fact, during the early commercialization phase, convincing customers to adopt the product of the industry is crucial. For adoption to take place, information dissemination and the creation of the industry infrastructure are critical (Moeen et al., 2020). Thus, strategic actions should be aimed at convincing organizations that are not yet part of the industry to enter, either as customers or to support the industry infrastructure (Agarwal et al., 2017). On the contrary, much of the actions that paradigm-driven ventures took to disseminate information that could help the industry move forward were focused on organizations that were already part of the industry. For example, collaboration downstream was still focused on technical co-development rather than widespread information dissemination. Moreover, their collective actions were still focused on gaining regulatory support rather than addressing organizations outside of the industry. The struggles of technology-driven ventures were more publicized and their delay in addressing new sources of uncertainty more easily recognized. Yet, both groups of ventures failed to address the constraints that prevented thin film from reaching maturity.

The second factor that prevented thin film emergence was the questioning of the existing knowledge base. This was a consequence of the strategy developed by technology-driven ventures and the decrease in complementarity between technology-driven and paradigm-driven strategies that began to address the same sources of uncertainty.

During early commercialization, technology-driven ventures missed most of the self-imposed technological milestones set during pre-commercialization. Despite the delays, they kept making announcements of efficiency records to prove technological development. The contrast between these record-breaking efficiency announcements and the inability to meet milestones on every other aspect of technical development led industry participants and the wider public to question whether these efficiency records could be trusted and whether thin film could deliver on its promises. Thus, while ventures released these records to show their technical strength, the outcome at the industry level was the generation of more technological uncertainty in the industry.

During early commercialization, the technology-driven and paradigm-driven strategies began to address the same sources of uncertainty, yet they favored very different approaches to technical development – technology-driven ventures boasted uncertified records while paradigm-driven ventures stressed the importance of testing for reliability. In November 2007, a group of American and European researchers published in the journal *Materials Today* to express their discontent on what they called "*reporting unrealistic and scientifically questionable" performance*". The publication was reported in IEEE Spectrum, a magazine specializing in technology and science news edited by the Institute of Electrical and Electronics Engineers, which sparked a wider debate surrounding the use of efficiency statements and their impact on the industry (Farley, 2008). Sean Shaheen, a physicist at the University of Denver commented, "*Truth in advertising is critical [...] The concern is that somebody starts investing money on a false claim and loses a lot of money, and therefore confidence in the field is shattered.*". Similarly, Shawn Williams, Plextronics' VP of technology released the following statement: "*It's about credibility. If people go out there and publish results that are not* *substantiated, then we or anyone else who's out there with real results get lost in the noise."* (Farley, 2008).

Paradigm-driven ventures never openly attacked technology-driven ventures per se, but they attacked the practice of releasing uncertified efficiency records that, at the time, was central to the technology-driven strategy. The paradigm-driven ventures hoped to develop common practices that would increase trust in the results released and, at the same time, facilitate building on the knowledge base that had been established so far. Yet, the debate around common practices backfired and led to the questioning of the efficiency records published and the methods used to obtain them. By addressing the same source of uncertainty with such different perspectives, technological uncertainty increased rather than decreased.

In conclusion, on the one hand, the mismatch between the strategies of the ventures and the pain points that were constraining mass manufacturing and commercialization slowed down the rate of uncertainty reduction. On the other hand, the factors that led to the questioning of the existing knowledge base led to the increase in technical uncertainty for existing and potential stakeholders. In turn, such questioning created the dynamics that prevented knowledge aggregation and that led to the questioning of the whole industry potential in the next phase.

5.5.3.3. Phase 3: retrenchment (2011-2014)

Solyndra's bankruptcy ushered in a period of ever-increasing uncertainty that led to the retrenchment of the thin film industry (Raffaelli, 2018). From a technical point of view, proving that volume manufacturing was possible was crucial to demonstrate that thin film could succeed commercially, despite the delays suffered during early commercialization. From a demand point of view, bankability, i.e. the ability to receive financing for large-scale solar projects using thin film, was crucial to increase market penetration in mainstream markets that could have helped thin film reach scale more quickly and gain demand (Bayus & Agarwal, 2002; Gort & Klepper, 1982). From a legitimacy point of view, Solyndra's bankruptcy was hotly debated as the venture had received a $535 Million loan guarantee from DOE to finance its manufacturing facility. As such, Solyndra's bankruptcy catalyzed the public opinion against thin film and the industry began losing momentum. Figure 3 (previously presented) presents the patterns of entry and exit in the industry and shows that after 2011, entry came to a halt and exits took over. The industry underwent many waves of exits: a first one after the beginning of the retrenchment phase (2011-2012), a second one in 2014 and another one in 2019.

Venture-level strategies and outcomes

Once in the retrenchment phase, technology-driven ventures attempted to reframe their strategy by highlighting how thin film and solar energy gave the country the opportunity to become independent from fossil fuels. Yet, their technology development was still focused on cost, efficiency and competition with silicon (Kaplan & Tripsas, 2008). The consequences of the strategy that they pursued for about a decade started to show. Incapable of moving down the technological curve and of raising further financing, many of these ventures went bankrupt or were acquired for much less than what had been invested into them. Nanosolar went bankrupt in 2013, Solopower ceased production in 2013. An attempt was made to revive the company in 2015 but it never restarted production and went bankrupt in 2018. Miasolè was acquired in 2013 for $30 Millions after it started reorganization.

The stigma surrounding the thin film industry affected also the paradigm-driven ventures. After 2011, they collaborated far less and also engaged in fewer collective actions. This is possibly due to the wave of bankruptcies that affected all firms in the thin film industry that led to a smaller pool of potential partners. The stigma surrounding thin film may have also hindered their attempts to collaborate with partners outside of the industry. During the retrenchment phase, they began making more vivid stories of their framing around fossil fuels and the possibility to become independent of the electricity grid, possibly in an attempt to contrast the negative publicity surrounding thin film, to gain the favor of the public and to raise resources (Martens & al., 2007). However, their attempts to create vivid stories around concepts such as a *World Without Wires* (Konarka) did not experience the same success that technology-driven ventures had during pre-commercialization. They too became increasingly incapable of raising financing. Konarka was acquired in 2012 and Plextronics began actively looking for an acquiror in 2013 and was acquired in 2014. In both cases, the technology was redirected to applications other than solar. Only Heliovolt went bankrupt in 2014.

Overall, once the industry entered the retrenchment phase, the ending of the story was already written. The strategies employed during pre-commercialization and early commercialization coupled with the loss in legitimacy catalyzed by Solyndra's bankruptcy made it increasingly difficult for ventures to raise the capital that they needed to scale up. This created a wave of bankruptcies for technology-driven ventures. Paradigm-driven ventures, while faring slightly better, decided to abandon the industry by looking for acquirers.

Industry-level dynamics and outcomes

At the industry level, the industry slowly began to retrench (Raffaelli, 2018). As Figure 2 (previously presented) illustrates, the share of thin film solar has been constantly decreasing starting from 2011. The industry was exited not only by the dominant ventures: multiple waves of exit took place. Firms in the industry either went bankrupt or decided to abandon thin film solar and re-direct their efforts to other industries (Figure 3).

The factors that led to the retrenchment were a continued mismatch between industry needs and strategies, the questioning of the industry potential and the lack of knowledge aggregation which prevented the development of the industry infrastructure[6]. The seeds of these dynamics were sown a decade before, during pre-commercialization (Roy et al., 2019).

[6] These factors are discussed in sequence for exposition purposes, but they influenced each other in a cycle that created the conditions that led to the retrenchment of the thin film industry.

As far as a mismatch between strategies and industry needs is concerned, bankability raised to prominence as the key source of demand uncertainty. Developing thin film to make it a bankable technology could have helped thin film in its attempts to scale up and gain demand (Bayus & Agarwal, 2002; Gort & Klepper, 1982). Despite its potential to save thin film, almost no venture addressed this issue. On the one hand, technology-driven ventures were ever more focused on technological uncertainty rather than demand uncertainty (Moeen et al., 2020). By doubling down on their efforts on cost and efficiency, they did not realize that bankability would have helped them gain traction with the customers of mainstream markets, whose size could have sustained scaling up. On the other hand, paradigm-driven ventures had their eyes set on overtaking the electricity grid and on distributed energy production at the site of consumption. Thus, they too failed to address the critical issue of bankability, which was more critical for centralized energy production. In fact, only Nanosolar attempted to address this issue and create a portfolio of projects that could prove the bankability of the technology.

Furthermore, the wave of bankruptcies in the industry contributed to increasing uncertainty around bankability as potential customers did not want to invest in thin film solar as the producers were expected to go bankrupt. In fact, "*many developers are hesitant to bank on CIGS, mostly because of big names loudly going bankrupt or closing (Solyndra, Nanosolar, Miasolé and most recently TSMC Solar)*" (Pickerel, 2016).

The strategies that led to questioning the knowledge base during early commercialization, coupled with the stigma ensuing from Solyndra's bankruptcy, led to the questioning of the industry potential during the retrenchment phase. As the industry potential became less and less promising, resource providers began to abandon thin film, which influenced the increase in exit and decrease in entry. As fewer organizations were left in the industry, the impetus for research and economic experimentation decreased. Thus, uncertainty reduction stalled.

Finally, the lack of knowledge aggregation – caused by actions taken in the pre-commercialization and early commercialization – prevented the development of the industry infrastructure that could have helped thin film commercialization (Adner & Kapoor, 2010; 2016). The "do it yourself" attitude of technology-driven ventures led to the existence of a multitude of technological trajectories for thin film manufacturing: "*exacerbating the problem, most thin-film manufacturers rely on custom-built production equipment*" (Stromsta, 2012). The many technological trajectories and the questioning of the technical knowledge base that took place during the early commercialization phase created rising uncertainty surrounding which trajectory would win or could be trusted. Not knowing which trajectory to back, equipment manufacturers did not enter the industry and thin film never developed the industry infrastructure necessary to reach cost-effective scale.

While during early commercialization, the strategies of the dominant ventures set off industry-level dynamics that slowed the emergence of the industry, during the retrenchment phase, industry-level dynamics inverted the direction of industry development and led to a loss of knowledge that made the thin film industry go from a promising, emerging industry to a disappearing niche. In 2016, Siva Power CTO commented that "*There is no money going into CIGS and all this learning, this technology, this supply chain … we're at risk of losing it*" (Pickerel, 2016). In 2017, the DOE announced "*an expanded focus on grid security, power electronics and early-stage research on concentrating solar power*" (Greenwire, 2017). Thus, the institutional support from which the thin film industry had benefitted during the pre-commercialization phase had now been redirected to other areas that were considered more promising for renewable energy.

Table 3 gives an overview of the strategies used by technology-driven and paradigm-driven ventures in the three phases and of the outcomes of these strategies.

Table 5-3 Overview of ventures' strategies and their outcomes at the venture and industry level

<table>
<tr><th colspan="2">Phase 1: Pre-commercialization
(2000-2007)</th><th colspan="2">Phase 2: Early commercialization
(2007-2011)</th><th colspan="2">Phase 3: Retrenchment
(2011-2014)</th></tr>
<tr><td>Technology-driven</td><td>Outcome</td><td>Technology-driven</td><td>Outcome</td><td>Technology-driven</td><td>Outcome</td></tr>
<tr><td>• Individual actions
• "Do it yourself" attitude
• Detailed and aggressive roadmap
• Prove technical strength</td><td>• Match with VC's business model → raise VC
• Vivid narrative → media attention → Main narrative of industry</td><td>• Individual actions
• "Do it yourself" attitude
• Detailed and aggressive roadmap
• Prove technical strength
• Conference attendance</td><td>• Missing milestones → difficulties raising VC
• Media question ability to deliver</td><td>• Individual actions
• "Do it yourself" attitude
• Partial reframing</td><td>• Missing milestones
• Inability to raise VC
• Bankruptcies</td></tr>
<tr><td colspan="2">Industry-level
• Ventures' strategies/Industry needs match → reduction of uncertainty, attention and resources to industry

• Complementary strategies with limited interaction → address complementary knowledge</td><td colspan="2">Industry-level
• Ventures' strategies/Industry needs mismatch → slowdown in uncertainty reduction
○ Tech-driven strategy on technical side
○ Paradigm-driven strategy on demand side

• Questioning of existing (technical) knowledge base → slowdown in uncertainty reduction
○ Tech-driven strategy missed milestones + efficiency records
○ Interaction of two strategies</td><td colspan="2">Industry-level
• Ventures' strategies/Industry needs mismatch → lack of demand uncertainty reduction

• No aggregation of technical knowledge→ No development of industry infrastructure
○ Too many technical trajectories

• Questioning of industry potential→Resource abandonment</td></tr>
<tr><td>Paradigm-driven</td><td>Outcome</td><td>Paradigm-driven</td><td>Outcome</td><td>Paradigm-driven</td><td>Outcome</td></tr>
<tr><td>• Individual collaborative actions
• "Borrow from others" attitude
• Collective actions (technical & regulatory focus)</td><td>• Mismatch with VC's business model → raise less VC and later
• Match with public-private interest → raise public money</td><td>• Individual collaborative actions
• "Borrow from others" attitude
• Collective actions (technical & regulatory focus)</td><td>• Match with public-private interest → raise public money</td><td>• Individual actions
• Decrease in collective actions</td><td>• Abandon industry</td></tr>
</table>

5.6. DISCUSSION

The findings show that the dominant ventures of the U.S. thin film solar industry used different industry triggers as anchors (Agarwal et al., 2017). As a consequence, they framed thin film and competition in vastly different ways (Kaplan & Tripsas, 2008) and engaged in contrasting strategies. Moreover, the findings show that these two strategies set off dynamics at the industry level that prevented thin film from reaching widespread commercialization. As a consequence, thin film retrenched rather than emerged to maturity (Agarwal & Bayus, 2002; Golder et al., 2009; Moeen et al., 2020).

The findings from this study have implications for the literature on industry evolution and emergence and for the literature on entrepreneurial cognition.

Prior work on industry evolution has underscored the key role played by start-ups in developing technologies and the industry infrastructure. Yet, it has largely examined entrepreneurial entrants as a homogeneous group (Bayus & Agarwal, 2007; Moeen, 2017). In contrast to this view, I find that the thin film dominant ventures pursued two different strategies. One group myopically focused on overtaking the old technology (Christensen, 1997) and the other group attempted to establish a new paradigm for energy production. Thereby, I join more recent scholarship that explores the sources of heterogeneity in de novo entrants (Furr, 2019; Agarwal & Shah, 2014). In contrast to the literature that traces the differences among ventures to their knowledge bases and the capabilities gained prior to joining the industry (Agarwal & Shah, 2014), I trace the source of heterogeneity to which industry trigger the ventures used to anchor their cognition and how they framed thin film (Agarwal et al., 2017; Benner & Tripsas, 2012; Kaplan & Tripsas, 2008).

The findings show that ventures anchoring thin film within the grand challenge of alleviating climate change explicitly envisioned the development of thin film as industry development. Accordingly, they purposefully engaged in strategic actions that would benefit the industry as a whole. For their individual actions, e.g. actions that benefit the venture

(Lashley & Pollock, 2019), they collaborated widely with others and were willing to borrow from other firms and also industries to address technical development. Especially collaboration with NREL contributed to releasing much of the technical knowledge that had been created by the ventures through publication of white papers. Thus, through their individual actions, they acquired, created and released knowledge that other actors could then use to further develop the technology (Moeen et al., 2020). For their collective actions, e.g. actions that benefit he industry (Lashley & Pollock, 2019), they worked on aggregating knowledge and collaborating to decide how to move forward to create a common knowledge base that would enable the industry to thrive (Moeen et al., 2020). Paradigm-driven ventures also lobbied for government support of their vision of the industry. Thus, in contrast to extant work that trace superior strategies to the ability of entrepreneurs to understand and adapt to changing circumstances (Eisenhardt & Bingham, 2017; Hannah & Eisenhardt, 2018), these ventures actively attempted to influence such changing circumstances rather than passively adapt and they tried to shape the environment to their favor.

In stark contrast, technology-driven ventures relied heavily on individual actions (Lashley & Pollock, 2019). I trace the origin of their strategy to the anchoring on scientific advancement (Agarwal et al., 2017) and to their framing of thin film as in competition with the old technology and their desire to show their technical strength (Christensen, 1997). The finding that these ventures engaged in little collaboration, especially during pre-commercialization, contrasts with the notion that the pre-commercialization phase is characterized by rich interaction between different actors to exchange ideas (Agarwal et al., 2017). Furthermore, the finding that the two strategies interacted little during pre-commercialization and that collaboration took place only within the paradigm-driven strategy rather than across strategies also contrasts with the notion of widespread collaboration during pre-commercialization. As I traced the limited willingness to collaborate of technology-driven ventures to how they framed thin film, the findings show that the cognition of the dominant ventures affects the extent to which actors in the industry are willing to collaborate and exchange ideas with others and also the extent to which they are willing to acquire ideas from others. These patterns of exchange can have long-term effects on the industry's ability to emerge, as shown by the retrenchment of thin film. Thus, I underscore the importance of cognition not only on venture-level outcomes but also on industry-level outcomes (Kaplan & Tripsas, 2008; Zuzul & Tripsas, 2019).

In the theoretical background, I claim that the literature on industry evolution has largely drawn from cases in which the industry successfully emerged. For this reason, we lack an understanding of those factors and strategies that can either prevent emergence or significantly delay it. In this study, I examine an industry that received widespread support from governments and the public, that attracted significant financial resources and, yet, was not only incapable of transitioning to maturity but retrenched and is at risk of disappearing (Raffaelli, 2018). With this study, I begin to unpack the factors that can contribute to industry non-emergence. First, the findings from this study show that the inability to transition to widespread commercialization is influenced by a multitude of factors. The key dynamics took place during the early commercialization phase: strategy mismatch and questioning of the technical knowledge base.

As industries progress, new sources of uncertainty emerge or gain importance (Moeen et al., 2020). Extant work has focused on those instances in which uncertainty was successfully addressed and decreased over time. The findings from this study contrast with this view. I find that a mismatch between the strategic actions of the dominant ventures and the evolution of the sources of uncertainty in the industry prevented the successful resolution of new uncertainty as it emerged. The mismatch began to form in the early commercialization phase when, for example, technology-driven ventures kept working to improve efficiency despite the rising importance of lifetime or stability. Surprisingly, the mismatch was created not only by delays in addressing new sources of uncertainty (as was the case with technology-driven ventures and lifetime) The findings also point to the possibility that mismatch is created by addressing sources of uncertainty too early. If a strategy addressing a source of uncertainty is not sustained until that source of uncertainty rises to prominence, uncertainty may not be fully resolved. This was the case with stability. Paradigm-driven ventures shone light on the issue with a consortium in 2004, during the pre-commercialization phase. Yet, as stability became a crucial issue during the early commercialization phase (after 2007), less work was dedicated to stability, preventing full resolution of this source of uncertainty. It is possible that addressing sources of uncertainty early on led ventures to believe that the uncertainty around stability had been resolved.

Prior work has highlighted the role of economic action to reduce uncertainty. With respect to technological uncertainty, extant research assumes that technical experimentation, both regarding different designs and the improvement of specific ones, has a positive impact on the industry (Roy et al., 2019; Tushman & Anderson, 1986; Utterback & Suárez, 1993). By experimenting with the technology and releasing the results of these experiments – via applying for patents, publishing white papers or publishing results, for instance – other actors in the industry can build on these efforts and further develop the technical knowledge of the industry (Roy et al., 2019). My findings on the consequences of the technology-driven strategy of releasing efficiency records and on how the interaction of the two strategies led to the questioning of the knowledge base contrast with this view that releasing knowledge has positive outcomes for the industry. In fact, during early commercialization, the release of efficiency records was called into question.

These findings highlight that strategies that have the purpose of reducing uncertainty may have unexpected consequences and contribute to increasing uncertainty. Moreover, they highlight that releasing knowledge may be counterproductive if there is no agreement in the industry with respect to the appropriate way to release such knowledge. This finding illuminates the potential tension between economic experimentation and reliability. On the one hand, the more experimentation takes place, the more knowledge is generated, the faster uncertainty is reduced and the sooner an industry emerges (Roy et al., 2019; Moeen et al., 2020). On the other hand, reliability is crucial for knowledge aggregation and calls for more focused experimentation or at least agreement on best practices for knowledge release.

Finally, the findings I discussed so far contribute to the growing literature examining how the actions taken during pre-commercialization can have long-lasting effect during post-commercialization (Moeen, 2017; Moeen & Mitchell, 2020; Roy et al., 2019). In fact, the dynamics that prevented the transition to widespread commercialization and led the industry to retrenchment (Raffaelli, 2018) can be traced back to strategies that had been developed before thin film had been commercialized. Moreover, it should be recognized that strategies may have unintended consequences in the long-term. The focus of technology-driven ventures on developing their own technology during pre-commercialization played a key role in enabling transition to commercialization. However, in the long term, they prevented the convergence on a standardized manufacturing method for thin films which, in turn, prevented entry from equipment manufacturers that could contribute to the creation of the value chain. Inadvertently, the strategy addressing technical uncertainty created conditions that prevented actors to rally around building industry infrastructure (Adner & Kapoor, 2016). Thus, actions that *deliberately* address one source of uncertainty may have *unintended consequences* on other dimensions.

With respect to the literature on entrepreneurial cognition and technological frames, extant work has explored how firms frame their technology once the product is on the market (Anthony et al., 2016; Benner & Tripsas, 2012) and the consequences of entrepreneurial cognition on the ventures itself (Furr, 2019; Zuzul & Tripsas, 2019).

The findings from this study illuminate how cognition also plays a role during the pre-commercialization. The findings show that the ventures differed in their interpretations of what the technology could do long before their technology variants were on the market. Moreover, the findings show that their interpretations can be traced back to the anchoring to different industry triggers and whether the ventures thought they were competing against the old technology or against the current method to generate and distribute electricity.

By carrying out a multi-level study of how the dominant ventures' strategies affected industry evolution, I show that the strategies that created the conditions for industry non-emergence can be traced back to the cognition of dominant ventures during pre-commercialization. This finding illuminates the notion that entrepreneurial cognition can also have repercussions at the industry level and begins to unpack the mechanisms linking entrepreneurial cognition to industry-level outcomes. Thus, it complements current research examining how cognition affects venture-level outcomes (Furr, 2019; Zuzul & Tripsas, 2019).

5.7. CONCLUSION

In this study, I set out to understand how the strategies of dominant ventures affect industry evolution, especially when an industry does not reach widespread commercialization. I performed a qualitative study using the micro-historical method that allowed me to give a contextualized account of past events and their outcomes (Hargadon, 2015). I find that dominant ventures differed in their framing of the technology and used contrasting strategies to bring it to market. During pre-commercialization the existence of two strategies that addressed technology commercialization differently, with little interaction between them, helped the industry to transition to commercialization but, once in the early commercialization phase, such different approaches and the increasing interaction between the two strategies set the stage for industry dynamics that led the industry to retrench rather than emerge.

6. CONCLUSION

This dissertation examines the antecedents of entrepreneurial ventures' technology commercialization on the product market and the consequences of different strategies on the ventures employing them and on the evolution of the industry.

I carry out three empirical studies that explore different aspects of technology commercialization on the product markets of entrepreneurial ventures. In studies 1 and 2 (chapters 2 and 3, respectively) I explore the drivers of such decisions under conditions of demand heterogeneity. In study 3 (chapter 4), I examine how dominant ventures commercializing on the product market developed different strategies and how these strategies affected industry development.

Study 1 examines the role of prior experience of the venture team on the decision to enter a niche product market. The results show that venture teams with higher prior experience in technical roles are less likely to choose niche product markets, while rich experience in marketing-related or entrepreneurial roles increases the likelihood that ventures choose such markets. Furthermore, the results show the contingent role of prior experience in the focal industry and show that when venture teams have gained prior technical experience in the industry they plan to re-enter, they become more attracted to niche markets than teams that gained technical experience elsewhere. Similarly, teams that gained prior marketing-related experience in the focal industry are more likely to choose niche product markets than teams that have gained such experience elsewhere.

The examination of the cognitive underpinnings of the decision to choose niche product markets provides a more nuanced picture of disruption (Christensen, 1997). More specifically, study 1 begins to unpack why disruption may not happen (Finkelstein & Sanford, 2000). In fact, disruption is rarely observed despite the widespread scholarly attention it has received.

Study 1 also shows that multiple product markets are characterized by different commercialization challenges, unlike the predictions of prior work on market entry choice that has equated product market with the whole industry. The results from this study show that ventures whose teams have prior technical experience are attracted by markets where complementary assets are consolidated and co-specialized to the old technology. This decision contrasts the predictions of the literature on market entry choice. By using a cognitive lens to explain this decision, study 1 contributes a complementary explanation to the current explanation for entry into product markets that highlights the role of market structure (Teece, 1986; Gans & Stern, 2003).

Finally, examining the findings of this study together with findings from prior work on the role of technical and marketing-related knowledge on the identification of potential markets for a technology (Gruber, MacMillan & Thompson, 2008 & 2013) points to a trade-off for these two types of prior experience between the ability to identify large sets of potential markets and the ability to choose truly disruptive ones.

Study 2 examines the role of industry-level factors and of the interaction between these factors and ventures' characteristics on the decision to enter markets with poor technology-market fit. Despite the risks associated with entering the wrong market, (Molner, Prabhu & Yadav, 2019; Shane, 2004), prior research provides little insight into why this happens. Study 2 sheds some light on why ventures would make such a choice. The results show that the more capital is available in the industry, the more ventures are likely to choose markets with poor technology-market fit. They also show that industry spinouts are more objective in their choices and that their incubation environment equipped them with a cognitive advantage that help them see beyond the cognitively biased demand landscape generated by increasing capital.

The results from this study contribute to the literature on technology commercialization of entrepreneurial ventures, entrepreneurial cognition and venture capital.

In contrast to prior work looking at the first step of technology-to-market linking, study 2 focuses on the second step of this process, i.e. the evaluation of markets to identify the most appropriate one. The decision to enter a market with poor fit may prevent the realization of the positive outcomes associated with identifying more potential markets (step one) or make the journey more complex. The results show that entering into the wrong market is the result of a cognitive bias at the industry level that affects the ability of ventures to see and evaluate demand heterogeneity (Adner & Levinthal, 2001).

In contrast to prior literature looking at the role of factors internal to the venture, e.g. prior experience, as the key drivers of entrepreneurial cognition and as constraining factors in market search, the results from this study illuminate the role of industry-level factors and on the interplay of these factors with ventures' characteristics on the cognition of ventures looking for and evaluating a market. While investment into the industry, via its creation of a cognitive bias, may render some markets cognitively invisible if investment make other part of the demand landscape more prominent, industry spinouts have a cognitive advantage that let them see beyond this bias in the industry and make more objective choices. Thus, I provide a set of factors affecting entrepreneurial cognition that is complementary to the existing ones focusing on actors inside the venture (Furr, 2019; Grégoire & Shepherd, 2012; Gruber et al., 2008;2013) and stakeholders' influence (Pahnke et al., 2015) and join recent research that has begun to study the role of events happening in the industry on firms' cognition (Benner & Tripsas, 2012).

The findings on industry spinouts also complement existing work on employee entrepreneurship that has focused on the capability advantage of these ventures. By showing that they also have a cognitive advantage, I provide a complementary explanation for their superior outcomes in terms of survival found by prior work (Agarwal & Shah, 2014; Klepper & Sleeper, 2005).

Finally, findings from study 2 paint a more nuanced picture of the role of venture capital for technological change. So far, much of the research on venture capital has underscored its positive effect but has largely focused on the ventures receiving it. I illuminate the potential for negative effects at the industry level. For ventures other than the ones receiving it, an influx of capital in the industry could lead them towards a choice which carries significant risks for their ability to bring a technology to market and also to survive. For markets, entry from ventures that cannot satisfy customers may drive customers away and prevent these markets from emerging.

Finally, recognizing that thin film solar largely failed to deliver on its promises and is retrenching rather than emerging as a new industry, in study 3, I set out to understand why this happened. The findings show that thin film dominant ventures developed two contrasting strategies that trace their origins back to how they cognitively framed the industry and technology. Moreover, the findings show that the existence of such contrasting views set some dynamics into action that led to a mismatch between what the industry needed to further emerge and what the strategies were addressing. This also led to the questioning of the existing knowledge base once thin film was in the commercialization phase. Over time, these two factors evolved and led to the questioning of the whole industry and inability to aggregate knowledge which prevented external actors along the value chain to rally around the industry and enter to develop the industry infrastructure.

This study contributes to the literature on industry evolution and the literature on cognition. In contrast to prior work that has focused on successful cases of industry emergence, I begin to unpack what factors prevent industry emergence. I find that entrepreneurial entrants are heterogeneous actors and I provide a cognitive explanation for such heterogeneity that is complementary to existing accounts of heterogeneity based on knowledge bases (Agarwal & Shah, 2014).

In contrast to the received wisdom that underscores the benefits of rich interaction between actors for an industry to emerge (Agarwal et al., 2017), the findings show that as the two strategies began to interact by addressing similar issues, their interaction generated more uncertainty than it solved. The findings also show that actions that address one source of uncertainty may have unintended consequences on other sources of uncertainty.

Taken together, the findings from the three studies included in this dissertation highlight the role played by demand heterogeneity (Adner & Levinthal, 2001; Priem et al., 2012) on the decisions to compete on the product market. They also underscore the role of cognition (Tripsas & Gavetti, 2000) on market entry decisions and strategy making on product markets. Finally, they provide some nuance on the role of factors that have so far been deemed positive for ventures and industries alike.

Studies 1 and 2 both highlight the importance of demand-side considerations and of not equating product market with industry. Study 1 shows that explicitly considering different markets in the industry enables us to see how commercialization challenges differ according to the type of market addressed, in contrast to previous explanations (Gans & Stern, 2003). Study 2 delves deeper into the issue of demand-side strategy and focuses on demand heterogeneity and its role on technology-to-market linking (Grégoire & Shepherd, 2012; Gruber et al., 2008;2013). Together, they point out that industries are more complex environments than prior work on technology commercialization has thought and that much heterogeneity exists within industries and not only between industries. Thus, these two studies join the renewed interest in exploring segmented industries (de Figueiredo & Silverman, 2007; Uzunca, 2018).

All the studies in this dissertation explore different facets of cognition and how they impact decision making. The results from studies 1 and 2 take two different perspectives on cognition but both underscore the its role in explaining decisions that seems counterintuitive. Study 1 focuses on the role of internal factors shaping cognition to explain why ventures may enter markets with consolidated complementary assets, a decision that cannot be explained in terms of market structure. Study 2 focuses on the external factors shaping cognition and uses them to provide an explanation for the decision to enter a market with poor technology-market fit. Finally, study 3 shows that the cognitive frames used by ventures carry long-term consequences both in terms of the strategies they use and in terms of industry outcomes.

Finally, studies 2 and 3 highlight the potential negative effects of factors that have been deemed positive for ventures and industries. Study 2 raises the question of the role of venture capital for the decisions of non-investees and for the emergence of markets. This is in contrast to prior work on venture capital that highlights its positive effects for investee ventures (Hellman & Puri, 2002). Study 3 highlights the unintended consequences of strategies addressing technical uncertainty during pre-commercialization on the lack of knowledge aggregation during post-commercialization and the inability to create the industry infrastructure necessary for industry emergence.

Taken together, the results of these two studies let us think more deeply about the unintended consequences of actions that seem beneficial. Study 2 highlights potential negative effects across different actors (investee vs. non-investee) and across levels of analysis (investee vs. market). Study 3 highlights potential negative effects across time. While both studies shed light on unintended negative effects, the opposite situation can also be true. While study 3 examines the failure of one industry to emerge and how investment seems to have gone to waste, the results of these experiments may be used in the future by other actors and by other industries. Thus, the failure of one industry may benefit another one.

7. REFERENCES

Abernathy, W.J., & Clark, K. B. 1985. Innovation: Mapping the winds of creative destruction. ***Research Policy***, 14(1), 3-22

Adams, P., Fontana, R., & Malerba, F. 2016. User-industry spinouts: Downstream industry knowledge as a source of new firm entry and survival. ***Organization Science***, 27(1): 18-35.

Adams, P., Fontana, R., & Malerba, F. 2019. Linking vertically related industries: entry by employee spinouts across industry boundaries. ***Industrial and Corporate Change***, 28(3): 529-550.

Adner, R., & Kapoor, R. 2010. Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. ***Strategic management journal***, 31(3): 306-333.

Adner, R., & Kapoor, R. 2016. Innovation ecosystems and the pace of substitution: Re-examining technology S-curves. ***Strategic management journal***, 37(4): 625-648.

Adner, R., & Levinthal, D. 2001. Demand heterogeneity and technology evolution: implications for product and process innovation. ***Management Science***, 47(5): 611-628.

Adner, R., & Snow, D. 2010. Old technology responses to new technology threats: demand heterogeneity and technology retreats. ***Industrial and Corporate Change***, 19(5): 1655-1675.

Adner, R., 2002. When are technologies disruptive? A demand-based view of the emergence of competition. ***Strategic Management Journal***, 23(8): 667-688.

Agarwal, R., & Bayus, B. L. 2002. The market evolution and sales takeoff of product innovations. **Management Science**, 48(8): 1024-1041.

Agarwal, R., & Shah, S. K. 2014. Knowledge sources of entrepreneurship: Firm formation by academic, user and employee innovators. ***Research Policy***, 43(7): 1109-1133.

Agarwal, R., Echambadi, R., Franco, A. M., & Sarkar, M. B. 2004. Knowledge transfer through inheritance: Spin-out generation, development, and survival. ***Academy of Management journal***, 47(4): 501-522.

Agarwal, R., Moeen, M., & Shah, S. 2017. Athena's birth: Triggers, actors, and actions preceding industry inception. **Strategic Entrepreneurship Journal**, 11(3): 287-305

Aldrich, H. E., & Fiol, C. M. 1994. Fools Rush in? The Institutional Context of Industry Creation. ***Academy of Management Review***, 19(4): 645-670.

Allison, P. D., & Christakis, N. A. 2006. Fixed-effects methods for the analysis of nonrepeated events. ***Sociological Methodology***, 36(1): 155-172.

Almandoz, J. 2012. Arriving at the starting line: The impact of community and financial logics on new banking ventures. ***Academy of Management Journal***, 55(6): 1381-1406.

Almandoz, J. 2014. Founding teams as carriers of competing logics: When institutional forces predict banks' risk exposure. ***Administrative Science Quarterly***, 59(3): 442-473.

Alvarez, S. A., & Busenitz, L. W. 2001. The entrepreneurship of resource-based theory. **Journal of Management**, 27(6): 755-775.

Andersen, P. K., & Gill, R. D. 1982. Cox's regression model for counting processes: a large sample study. ***The annals of statistics***: 1100-1120.

Anthony, C., Nelson, A. J., & Tripsas, M. 2016. "Who Are You?… I Really Wanna Know": Product Meaning and Competitive Positioning in the Nascent Synthesizer Industry. ***Strategy Science***, 1(3): 163-183.

Ardani, K., & Margolis, R. 2010. Solar Technologies Market Report: Narional Renewable Energy Laboratory.

Arora, A., & Ceccagnoli, M. 2006. Patent protection, complementary assets, and firms' incentives for technology licensing. ***Management Science***, 52(2): 293-308.

Arora, A., Fosfuri, A. & Gambardella, A. 2001. Markets for technology and their implications for corporate strategy. ***Industrial and Corporate Change***, 10(2): 419-451

Barnett, W. P., Swanson, A. N., & Sorenson, O. 2003. Asymmetric selection among organizations. ***Industrial and Corporate Change***, 12(4): 673-695.

Baron, R. A., & Ensley, M. D. 2006. Opportunity recognition as the detection of meaningful patterns: Evidence from comparisons of novice and experienced entrepreneurs. ***Management science***, 52(9): 1331-1344.

Barron, R., 2008. Miasolé clears the air. GreentechMedia.com. May 9.

Bayus, B. L., & Agarwal, R. 2007. The role of pre-entry experience, entry timing, and product technology strategies in explaining firm survival. ***Management Science***, 53(12): 1887-1902.

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

Beckman, C. M., & Burton, M. D. 2008. Founding the future: Path dependence in the evolution of top management teams from founding to IPO. ***Organization Science***, 19(1): 3-24.

Beckman, C. M., Burton, M. D., & 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, M. J., & Tripsas, M. 2012. The influence of prior industry affiliation on framing in nascent industries: the evolution of digital cameras. ***Strategic Management Journal***, 33(3): 277-302.

Bingham, C. B., & Eisenhardt, K. M. 2011. Rational heuristics: The 'simple rules' that strategists learn from process experience. ***Strategic Management Journal***, 32(13): 1437-1464.

Boeker, W. 1988. Organizational origins: Entrepreneurial and environmental imprinting of the time of founding. ***Ecological models of organizations***: 33-51.

Bogner, W.C. &, Barr, P.S. 2000. Making Sense in Hypercompetitive Environments: A Cognitive Explanation for the Persistence of High Velocity Competition. ***Organization Science***, 11(2), 212-226.

Casey, T., 2016. Siva Says "Scale Up!" For Low Cost Solar In USA. CleanTechnica, May 4.

Chernova, Y. 2008 b. Total Invests $45M In Konarka For 20% Stake. Clean Technology Insight, December 16.

Chernova, Y., 2007. Miasole Starts Shipping After Raising About $50M In Series D. Clean Technology Insight, September 26.

Chernova, Y., 2008 a. Backed By $600M Solyndra's Building New CIGS Facility. Clean Technology Insight, October 7.

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. 1997. ***The Innovator's Dilemma***. Harvard Business School Press: Boston, MA

Christensen, C. M., & Bower, J. L. 1996. Customer power, strategic investment, and the failure of leading firms. ***Strategic management journal***, 17(3): 197-218.

Colombo, M. G., Grilli, L., & Piva, E. 2006. In search of complementary assets: The determinants of alliance formation of high-tech start-ups. ***Research policy***, 35(8): 1166-1199.

Cox, D. R. 1972. Regression models and life-tables. ***Journal of the Royal Statistical Society: Series B (Methodological)***, 34(2): 187-202.

Cox, D. R. 2018. ***Analysis of survival data***: Routledge.

Daft, R. L. & Weick, K. E. 1984. Toward a model of organizations as interpretation systems. ***Academy of Management Review***, 9(2): 284–295.
Dahl, M. S., & Sorenson, O. 2012. Home sweet home: Entrepreneurs' location choices and the performance of their ventures. ***Management Science***, 58(6): 1059-1071.
Dane, E. 2010. Reconsidering the trade-off between expertise and flexibility: A cognitive entrenchment perspective. ***Academy of Management Review***, 35(4): 579-603.
Danneels, E. 2004. Disruptive technology reconsidered: A critique and research agenda. ***Journal of product innovation management***, 21(4): 246-258.
Danneels, E. 2007. The process of technological competence leveraging. ***Strategic Management Journal,*** 28(5): 511-533.
Danneels, E. 2008. Organizational antecedents of second-order competences. ***Strategic management journal***, 29(5): 519-543.
de Figueiredo, J. M., & Silverman, B. S. 2007. Churn, baby, churn: Strategic dynamics among dominant and fringe firms in a segmented industry. ***Management Science***, 53(4): 632-650.
Dunbar, K., & Fugelsang, J. 2005. Scientific thinking and reasoning. ***The Cambridge handbook of thinking and reasoning***: 705-725.
Eggers, J. P. 2014. Competing technologies and industry evolution: The benefits of making mistakes in the flat panel display industry. ***Strategic Management Journal***, 35(2): 159-178.
Eggers, J., & Song, L. 2015. Dealing with failure: Serial entrepreneurs and the costs of changing industries between ventures. ***Academy of Management Journal***, 58(6): 1785-1803.
Eisenhardt, K. M. 1989. Making fast strategic decisions in high-velocity environments. ***Academy of Management Journal***, 32(3): 543–576
Eisenhardt, K. M., & Schoonhoven, C. B. 1990. Organizational growth: Linking founding team, strategy, environment, and growth among US semiconductor ventures, 1978-1988. ***Administrative Science Quarterly***, 35(3): 504-529.
Eisenhardt, K. M., & Bingham, C. B. 2017. Superior Strategy in Entrepreneurial Settings: Thinking, Doing, and the Logic of Opportunity. ***Strategy Science***, 2(4):246-257
Fahey, J. 2010. A Second Chance For Novel Solar. Forbes. March 1.
Farley, P. 2008. Solar-Cell Squabble; Organic photovoltaics could be dirt cheap, but their efficiency is in dispute. IEEE Spectrum. April 1.
Fehrenbacher, K., 2008. 10 Solar Startups to Watch at Solar Power International. Earth2Tech.com, October 13.
Fern, M. J., Cardinal, L. B., & O'Neill, H. M. 2012. The genesis of strategy in new ventures: escaping the constraints of founder and team knowledge. ***Strategic Management Journal***, 33(4): 427-447.
Ferraro, F., Etzion, D., & Gehman, J. 2015. Tackling grand challenges pragmatically: Robust action revisited. ***Organization Studies***, 36(3): 363–390.
Fialka, J. 2018. Solar Industry's Future Lies in Lightweight Technology, ***E&E News***
Finkelstein, S., & Sanford, S. H. 2000. Learning from corporate mistakes: The rise and fall of Iridium. ***Organizational Dynamics***, 29(2): 138-148.
Finkelstein, S., Hambrick, D. C., & Cannella, A. A. 2009. ***Strategic leadership: Theory and research on executives, top management teams, and boards***: Oxford University Press
Fisher, G., Kuratko, D. F., Bloodgood, J. M., & Hornsby, J. F. 2017. Legitimate to whom? The challenge of audience diversity and new venture legitimacy. **Journal of Business Venturing**, 32(1): 52-71
Furr, N. R. 2019. Product Adaptation During New Industry Emergence: The Role of Start-Up Team Preentry Experience. ***Organization Science***, 30(5): 1076-1096.

Furr, N., & Kapoor, R. 2018. Capabilities, technologies, and firm exit during industry shakeout: Evidence from the global solar photovoltaic industry. ***Strategic Management Journal***, 39(1): 33-61.

Furr, N., Cavarretta, F., & Garg, S. 2012. Who changes course? The role of domain knowledge and novel framing in making technology changes. ***Strategic Entrepreneurship Journal***, 6(3): 236-256.

Gambardella, A., & Giarratana, M. 2006. Innovations for Products, Innovations for Licensing: Patents and Downstream Assets in the Software Security Industry. ***working paper***.

Gans, J. 2016. ***The disruption dilemma***: MIT Press.

Gans, J. S., & Stern, S. 2003. The product market and the market for "ideas": Commercialization strategies for technology entrepreneurs. ***Research Policy***, 32(2 SPEC.): 333-350.

Gans, J. S., & Stern, S. 2010. Is there a market for ideas? ***Industrial and Corporate Change,*** 19(3): 805-837**.**

Gavetti G., Levinthal D. A. 2000. Looking forward and looking backward: cognitive and experiential search. ***Administrative Science Quarterly***, 45(1): 113–137

Gavetti, G., & Rivkin, J. W. 2007. On the origin of strategy: Action and cognition over time. ***Organization Science***, 18(3): 420-439.

Gilboa, I., & Schmeidler, D. 2001. ***A theory of case-based decisions***: Cambridge University Press.

Golder, P. N., & Tellis, G. J. 1997. Will it ever fly? Modeling the takeoff of really new consumer durables. ***Marketing Science***, 16(3): 256-270.

Golder, P. N., Shacham, R., & Mitra, D. 2009. Innovations' Origins: When, By Whom, and How Are Radical Innovations Developed? ***Marketing Science***, 28(1): 166-179.

Gort, M., & Klepper, S. 1982. Time paths in the diffusion of product innovations. ***The Economic Journal***, 92(367): 630-653.

Grégoire, D. A., & Shepherd, D. A. 2012. Technology-market combinations and the identification of entrepreneurial opportunities: An investigation of the opportunity-individual nexus. ***Academy of Management Journal***, 55(4): 753-785.

Grodal, S., & O'Mahony, S., 2017. How does a grand challenge become displaced? Explaining the duality of field mobilization. **Academy of Management Journal**, 60(5), 1801-1827.

Groom, N. 2011. Solar start-ups turn to big companies for capital. Reuter News. 6 April 2011

Gruber, M. & MacMillan, I. C. 2017. Entrepreneurial Behavior: A Reconceptualization and Extension Based on Identity Theory. ***Strategic Entrepreneurship Journal***, 11(3): 271-286.

Gruber, M., MacMillan, I. C., & Thompson, J. D. 2008. Look before you leap: Market opportunity identification in emerging technology firms. ***Management Science***, 54(9): 1652-1665.

Gruber, M., MacMillan, I. C., & Thompson, J. D. 2012. From minds to markets how human capital endowments shape market opportunity identification of technology start-ups. ***Journal of Management***, 38(5): 1421-1449.

Gruber, M., MacMillan, I. C., & Thompson, J. D. 2013. Escaping the prior knowledge corridor: What shapes the number and variety of market opportunities identified before market entry of technology start-ups? ***Organization Science***, 24(1): 280-300.

Hambrick, D. C., Finkelstein, S., & Mooney, A. C. 2005. Executive job demands: New insights for explaining strategic decisions and leader behaviors. ***Academy of management review***, 30(3): 472-491.

Hannah, D. P., & Eisenhardt, K. M. 2018. How firms navigate cooperation and competition in nascent ecosystems. ***Strategic Management Journal***, 39(12): 3163-3192.

Hannan, M. T., & Freeman, J. 1977. The population ecology of organizations. ***American journal of sociology***, 82(5): 929-964.
Hargadon, A. 2015. From What Happened to What Happens. **Handbook of Qualitative Organizational Research: Innovative Pathways and Methods**: 122.
Hargadon, A. B., & Douglas, Y. 2001. When innovations meet institutions: Edison and the design of the electric light. ***Administrative Science Quarterly***, 46(3): 476-501.
Hellmann, T., & Puri, M. 2002. Venture capital and the professionalization of start-up firms: Empirical evidence. ***Journal of Finance***, 57(1): 169-197.
James, T., Goodrich, A., Woodhouse, M., Margolis, R., & Ong, S. 2011. **Building-Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices**. NREL.
Jick, T.D. 1979. Mixing qualitative and quantitative methods: Triangulation in action. ***Administrative Science Quarterly***, 24(4): 602–611.
Jones, G. G., & Bouamane, L. 2012. " Power from Sunshine": A Business History of Solar Energy.
Kanellos, M., 2006 a. Silicon vs. CIGS: With solar energy, the issue is material; What should solar panels be made of? Silicon has history on its side, but the future may lie in CIGS. CNET News.com, October 2.
Kanellos, M., 2006 b. Solar start-up snags $35 million as CIGS ignites; Will CIGS technology challenge silicon in solar panels? Venture capitalists are helping fuel the debate. CNET News.com. October 27.
Kanellos, M., 2008. CIGS cell makers battle it out for efficiency crown; Global Solar says it's number one in solar cells made from copper indium gallium selenide, but so does Nanosolar. CNET News.com, January 27.
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., & Murray, F. 2010. Entrepreneurship and the construction of value in biotechnology, Technology and Organization: Essays in Honour of Joan Woodward: 107-147: Emerald Group Publishing Limited.
Kaplan, S., & Tripsas, M. 2008. Thinking about technology: Applying a cognitive lens to technical change. ***Research Policy***, 37(5): 790-805.
Kaplan, S., Murray, F., & Henderson, R. 2003. Discontinuities and senior management: assessing the role of recognition in pharmaceutical firm response to biotechnology. ***Industrial and Corporate Change***, 12(2): 203-233.
Kapoor, R., & Furr, N. R. 2015. Complementarities and competition: Unpacking the drivers of entrants' technology choices in the solar photovoltaic industry. ***Strategic Management Journal***, 36(3): 416-436.
Kazanjian, R. K. 1988. Relation of dominant problems to stages of growth in technology-based new ventures. ***Academy of management journal***, 31(2): 257-279.
Klepper, S. 2002 a. Firm survival and the evolution of oligopoly. ***RAND Journal of Economics***: 37-61.
Klepper, S. 2002 b. The capabilities of new firms and the evolution of the US automobile industry. ***Industrial and Corporate Change***, 11(4): 645-666.
Klepper, S., & Sleeper, S. 2005. Entry by spinoffs. ***Management Science***, 51(8): 1291-1306.
Klepper, S., & Thompson, P. 2006. Submarkets and the evolution of market structure. ***The RAND Journal of Economics***, 37(4): 861-886.
KnwledgeTransferNetwork. 2013. UK Solar Photovoltaic Roadmap: ESP KTN.
Langley, A. 1999. Strategies for theorizing from process data. ***Academy of Management Review,*** 24(4): 691-710.

Lashley, K., & Pollock, T. G., 2019. Waiting to Inhale: Reducing Stigma in the Medical Cannabis Industry. ***Administrative Science Quarterly***.

Lawrence, T. B. 1999. Institutional strategy. ***Journal of management***, 25(2): 161-187.

Levinthal, D. A. 1998. The slow pace of rapid technological change: gradualism and punctuation in technological change. ***Industrial and Corporate Change***, 7(2): 217-47

Lin, D. Y., & Wei, L.-J. 1989. The robust inference for the Cox proportional hazards model. ***Journal of the American statistical Association***, 84(408): 1074-1078.

Lounsbury, M., & Glynn, M. A. 2001. Cultural entrepreneurship: Stories, legitimacy, and the acquisition of resources. ***Strategic Management Journal***, 22(6-7): 545-564.

Martens, M. L., Jennings, J. E., & Jennings, P. D. 2007. Do the stories they tell get them the money they need? The role of entrepreneurial narratives in resource acquisition. ***Academy of Management Journal***, 50(5): 1107-1132.

Marx, M., Gans, J. S., & Hsu, D. H. 2014. Dynamic commercialization strategies for disruptive technologies: Evidence from the speech recognition industry. ***Management Science***, 60(12): 3103-3123.

McDonald, R. & Gao, C. 2019. Pivoting Isn't Enough? Managing Strategic Reorientation in New Ventures. ***Organization Science***, 30(6):1289-1318.

Moeen, M. 2017. Entry into nascent industries: disentangling a firm's capability portfolio at the time of investment versus market entry. ***Strategic Management Journal***, 38(10): 1986-2004.

Moeen, M., & Agarwal, R. 2017. Incubation of an industry: Heterogeneous knowledge bases and modes of value capture. ***Strategic Management Journal***, 38(3): 566-587.

Moeen, M., & Mitchell, W. 2020. How do pre-entrants to the industry incubation stage choose between alliances and acquisitions for technical capabilities and specialized complementary assets? ***Strategic Management Journal***.

Moeen, M., Agarwal, R., & Shah, S. 2020. Building Industries by Building Knowledge: Uncertainty Reduction Over Industry Milestones. ***Strategy Science*, **5(3): 218-244

Molner, S., Prabhu, J. C., & Yadav, M. S. 2019. Lost in a Universe of Markets: Toward a Theory of Market Scoping for Early-Stage Technologies. ***Journal of Marketing***, 83(2): 37-61.

Nadkarni, S. & Barr P.S. 2008. Environmental Context, Managerial Cognition, and Strategic Action: An Integrated View, ***Strategic Management Journal***, 29(13): 1395-1427

Neter, J., Kutner, M. H., Nachtsheim, C. J., & Wasserman, W. 1996. Applied linear statistical methods. ***Irwin, Chicago***.

O'Rourke, S., Kim, P., & Polavarapu, H. 2007. Technology and economics: thin films and crystalline silicon: Deutsche Bank.

O'brien, R. M. 2007. A caution regarding rules of thumb for variance inflation factors. ***Quality & quantity***, 41(5): 673-690.

Ocasio, W. 1997. Towards an attention-based view of the firm. ***Strategic management journal***, 18(S1): 187-206.

Osborne, J., & Hinckley, A. 2007. Alternative Energy Outlook: CIBC WorldMarket.

Pahnke, E. C., Katila, R., & Eisenhardt, K. M. 2015. Who takes you to the dance? How partners' institutional logics influence innovation in young firms. ***Administrative Science Quarterly***, 60(4): 596-633.

Penrose, E. T. 1959. ***The theory of the growth of the firm***. Cambridge, MA.

Peters, T. S., & Thiel, J. 2016. P Strategy and Use of IP Protection Mechanisms Across Firm Size: An Empirical Investigation. ***Academy of Management Proceedings***, 2016(1): 17693.

Petkova, A. P., Wadhwa, A., Yao, X., & Jain, S., 2014. Reputation and decision making under ambiguity: a study of U.S. venture capital firms' investments in the emerging clean energy sector. ***Academy of Management Journal***, 50(2): 422-448

Pickerel, K. 2016. CIGS thin film: Solar's black sheep is finding its feet. Solar Power World, January 4.

Pinch, T. J., & Bijker, W. E. 1984. The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other. Social studies of science, 14(3): 399-441.

Pontikes, E. G., & Barnett, W. P. 2017. The non-consensus entrepreneur: Organizational responses to vital events. ***Administrative Science Quarterly***, 62(1): 140-178.

Porter, M. E. 1985. ***Competitive advantage: creating and sustaining superior performance***. New York: FreePress, 43: 214.

Priem, R. L. 1994. Executive judgment, organizational congruence and firm performance. Organization Science, 5(3): 421-437.

Priem, R. L., 2007. A consumer perspective on value creation. ***Academy of Management Review***, 32(19: 219–235.

Priem, R. L., Li, S., & Carr, j. 2012. Insights and New Directions from Demand-Side Approaches to Technology Innovation, Entrepreneurship, and Strategic Management Research. ***Journal of Management***, 38(1): 346-374

Qian, L., Agarwal, R., & Hoetker, G. 2012. Configuration of value chain activities: the effect of pre-entry capabilities, transaction hazards, and industry evolution on decisions to internalize. ***Organization Science***, 23(5): 1330-1349.

Raffaelli, R., 2018. Technology reemergence: creating new value for old technologies in Swiss mechanical watchmaking, 1970-2008. **Administrative Science Quarterly**, 64(3): 576-618.

Rao, H. 2004. Institutional activism in the early American automobile industry. ***Journal of Business Venturing***, 19(3): 359-384.

Ritch, E., 2008. Solyndra reveals thin film solar tubes. CleanTech Group. October 6.

Rivlin, G., 2005. Green Tinge Is Attracting Seed Money To Ventures. The New York Times. June 22.

Rothaermel, F. T. & Hill, C. W. 2005. Technological discontinuities and complementary assets: a longitudinal study of industry and firm performance. ***Organization Science***, 16(1): 52-70

Roy, R., Lampert, C. M., & Sarkar, M. B., 2019. The Pre-Commercialization Emergence of the Combination of Product Features in the Charge-Coupled Device Image Sensor. ***Strategic Entrepreneurship Journal***, 13(4): 448-477

Santos, F. M., & Eisenhardt, K. M. 2009. Constructing markets and shaping boundaries: Entrepreneurial power in nascent fields. ***Academy of Management Journal***, 52(4): 643-671.

Schumpeter, J. A. 1934. ***The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle***: Transaction publishers.

Shah, S. K., & 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.

Shane, S. A. 2004. ***Academic entrepreneurship: University spinoffs and wealth creation***: Edward Elgar Publishing.

Sheahan, M., 2005. VCs Have a Sunny Outlook for Solar Energy Investments. Private Equity Week. June 27.

Shepherd, D. A., Souitaris, V., & Gruber, M. 2020. Creating New Ventures: A Review and Research Agenda. ***Journal of Management***.

Shermon, A., & Moeen, M. 2020. Zooming Out or Zooming In? Entrants' Product Market Breadth in the Nascent Drone Industry. ***Working paper.***

Sirmon, D. G., Hitt, M. A., & Ireland, R. D. 2007. Managing firm resources in dynamic environments to create value: Looking inside the black box. ***Academy of management review***, 32(1): 273-292.

SolarServer. 2010. Building Integrated Photovoltaics: An emerging market.

Stromsta, K.-E. 2012. In Depth: Some rays of light amid the gloom for thin-film PV Recharge News. May 21.

Stuart, T.E., Hoang, H., & Hybels, R.C., 1999. Interorganizational endorsements and the performance of entrepreneurial ventures. ***Administrative Science Quarterly***, 44(2); 315-349

Teece, D. J. 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. ***Research Policy***, 15(6): 285-305.

Thomas, D. E., Eden, L., Hitt, M. A., & Miller, S. R. 2007. Experience of emerging market firms: The role of cognitive bias in developed market entry and survival. ***Management International Review***, 47(6): 845-867.

Tripsas, M. 1997. Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry. ***Strategic Management Journal***, 18(S1): 119-142.

Tripsas, M. 2008. Customer preference discontinuities: A trigger for radical technological change. ***Managerial and decision economics***, 29(2-3): 79-97.

Tripsas, M., & Gavetti, G. 2000. Capabilities, Cognition, and Inertia: Evidence from Digital Imaging. ***Strategic Management Journal***, 21(10/11), 1147-1161

Tushman, M. L., & Anderson, P. 1986. Technological discontinuities and organizational environments. ***Administrative Science Quarterly***: 439-465.

Utterback, J. M., & Suárez, F. F. 1993. Innovation, competition, and industry structure. **Research policy**, 22(1): 1-21.

Uzunca, B. 2018. A Competence-Based View of Industry Evolution: The Impact of Submarket Convergence on Incumbent− Entrant Dynamics. ***Academy of Management Journal***, 61(2): 738-768.

Valliere, D., & Peterson, R. 2004. Inflating the bubble: examining dot-com investor behaviour. ***Venture Capital***, 6(1): 1-22.

van Osselaer, S. M. J., Ramanathan, S., Campbell, M. C., Cohen, J. B., Dale, J. K., Herr, P. M., & Tavassoli, N. T. 2005. Choice based on goals. ***Marketing Letters***, 16(3–4): 335–346.

Vinokurova, N. 2019. Reshaping demand landscapes: How firms change customer preferences to better fit their products. ***Strategic Management Journal***, 40(13): 2107-2137

Ward, T. B. 2004. Cognition, creativity, and entrepreneurship. ***Journal of business venturing***, 19(2): 173-188.

Zahra, S. A., Van de Velde, E., & Larraneta, B. 2007. Knowledge conversion capability and the performance of corporate and university spin-offs. ***Industrial and Corporate Change***, 16(4): 569-608.

Zanetti, I. 2010. Sustainable renovation of historical buildings concepts for solar integration. Paper presented at the Solar Building Skins Energy Forum. Bressanone, Italy.

Zelner, B. A. 2009. Using simulation to interpret results from logit, probit, and other nonlinear models. ***Strategic Management Journal***, 30(12): 1335-1348.

Zuzul, T., & Tripsas, M. 2019. Start-up inertia versus flexibility: The role of founder identity in a nascent industry. ***Administrative Science Quarterly***, 65(2): 395-433.

8. APPENDIX

Table 8-1 Evaluation criteria for solar PV technologies

Criteria	Explanation
Efficiency	Percentage of sunlight turned into electricity at peak-sunlight
Cost	Cost per watt (e.g. Dollar per Watt, Euro per Watt)
Weight	How heavy the solar cell is
Thickness	How thick the solar cell is
Flexibility	Whether the solar cell is rigid or can be folded
Transparency	How transparent the solar cell is
Reliability/stability/predictability	Ability to offer stable performance over time
Lifetime/durability	Ability of solar cell to operate for a long period of time (typical requirement is 25 years)
Fragility	How easily the solar cell breaks
Design form/form factor/aesthetic	Versatility from the point of view of design (e.g. color, shape, customization)
Light-spectrum performance	Ability to transform sunlight into electricity at different levels of light (e.g. low-light performance)
Installation	How time-intensive, costly and effort-intensive the installation of solar panels based on a specific technology is
Temperature performance	Ability to perform and not degrade in extreme temperatures (e.g. cold- and high-temperature performance)

Table 8-2 Evaluation criteria for solar PV technologies by market

Market	Criteria	Explanation
Residential rooftop systems	• High efficiency • Low cost • High durability/lifespan	Rooftop systems require high upfront costs for design and installation. The upfront investment is more easily justified when the system can produce energy for a long number of years. Thus, customers value high efficiency (to reduce electricity costs as much as possible), low cost and high durability. These three criteria enable customers to recuperate their investment in a shorter amount of time. Reliability is also key to ensure that the system generates energy for a long time span (typically 20-25 years)
Commercial rooftop systems	• High efficiency • Low cost • High durability/lifespan Weight	Similar to residential rooftop systems, commercial residential systems value high efficiency, cost and lifespan. Additionally, they also place value on weight. Many commercial rooftops cannot support the load of a solar PV system. Thus, weight is an important criterion to enable installation on commercial rooftop.

Ground-mounted systems	• Low cost • High reliability • High efficiency	Ground-mounted systems are large-scale installations that are built to feed electricity into the grid. Thus, they are usually built by specialized firms that develop, build (and often operate) them as an investment to generate a return. To construct one of these systems, investment is typically necessary. Thus, the panels used in the system needs to be bankable. For this reason, firms constructing these systems value cost and efficiency to attract equity. As they feed into the grid, reliability is also crucial because it guarantees that the PV system will produce a constant energy flow.
Solar tiles	• Weight • Form factor • Efficiency	As one of the building-integrated PV markets (BIPV), solar tiles are used in green buildings. Customers are typically less sensitive to cost. Weight and form factor (design/aesthetic) are important criteria used to evaluate technologies in this market because solar tiles have the goal to replace traditional tiles. For this reason, solar tiles need to be available in shapes and designs that can fit different architectural styles. Efficiency is not as important as in a rooftop system because solar tiles can cover the entire roof. Thus, the area trades off with the efficiency.
Building façade	• Flexibility • Thickness • Form factor • Efficiency	As one of the building-integrated PV markets (BIPV), Building façades are used in green buildings. Customers are typically less sensitive to cost. In this market, the goal is to design aesthetically pleasing façades. Thus, key criteria are flexibility, thickness and form factor because they enable architects to design creative solutions. Efficiency is not a critical factor because in BIPV solar PV can be deployed to cover the entire building and the entire building produces energy from the sun, and area compensates for efficiency.
Solar glass	• Transparency • Form factor	As one of the building-integrated PV markets (BIPV), solar glass is used in green buildings. Customers are typically less sensitive to cost. Customers' key criteria for evaluation is transparency. Followed by form factor such as color. Transparency is critical because solar glass is used in solar windows and other architectural elements that need to let light into a building.
Solar floor	• Fragility • Light-spectrum performance	As one of the building-integrated PV markets (BIPV), solar floor is used in green buildings. Customers are typically less sensitive to cost.

		Solar floors need to be durable and perform in different light conditions, for example inside or in shaded areas. Thus, key criteria are fragility and light-spectrum performance.
Off-grid	• Cost • Durability • Reliability • Efficiency	Off-grid applications are solar systems that are used to power buildings in isolated areas that are not reached by the grid. Cost is important to enable customers to make the investment. Durability and reliability are important because these systems need to provide a constant stream of energy (reliability) to a building that doesn't have another source of electricity and will need to do so for a long period of time (durability) to justify the investment. Efficiency is important to guarantee power to the building.
Canopy/shelters	• Flexibility • Form factors	In this market, flexibility and form factor are important criteria used to evaluate solar PV technologies. Flexibility is important because close integration into fabric-like materials is a goal in this market. Form factor is important because it allows for design versatility.
Military	• Weight • Flexibility • Reliability	The goal in this market is to have portable energy for troops. Weight and flexibility are key for enabling portability. Finally, reliability is important because the solar technology needs to guarantee that it will work.
Consumer electronics	• Weight • Flexibility	Easy integration into a product is the goal in this market. As a consequence, weight and flexibility are critical criteria because they facilitate integration.
Indoor applications	• Light-spectrum performance (low-light performance) • Form factor	In this market, low-light performance is particularly important as the PV technology will be deployed inside. Form factor is important because the PV technology needs to be integrated into the house.
Chargers	• Weight • Flexibility • Light-spectrum performance	Similar to consumer electronics, easy integration is important in this market. Thus, weight and flexibility are important criteria used to evaluate technologies. Given that chargers are used in multiple situations indoors, performance in a wide range of the light spectrum is another important criterion. Finally, efficiency is not as important in this market because the solar PV technology needs to guarantee only a "trickle of energy" to power electronics.
Vehicles	• Weight • Flexibility • Form factors	In this market, integration and aesthetic are two key goals. In line with the first goal, weight and flexibility are important because they enable integration into the vehicle. In line with the

		second goal, form factor is also important because it enables creativity in design.
Aerospace	• Weight	Weight is the most important criterion for aerospace applications because weight determines the amount of fuel necessary to launch satellites. The less a satellite weighs, the less fuel is needed.
Solar fabric	• Flexibility	For the solar fabric market, close integration between the technology and the fabric is important. A key goal is to have solar fabric be as similar to a traditional fabric as possible. To this end, flexibility of the solar PV technology is critical.
Lights/lamps	• Light-spectrum performance (low-light performance) • Flexibility • Weight	Light-spectrum performance such as low-light performance is important to guarantee electricity over the course of the day. Flexibility and weight are important criteria to have close integration.
Sails	• Flexibility • Weight	This market shares some similarities with the solar fabric market in that the technology needs to be as flexible as possible to enable integration with the sails. Weight is also important here because heavy sail would impact the design of a boat.
Pumps	• Cost • Durability	This market shares some similarity with the off-grid market in that cost is important for affordability. Durability is also important to provide energy over a long period of time.

Table 8-3 Overview of solar PV technologies and their performance

Technology	**Description of performance**	**Attributes of performance**
First-generation	First-generation technologies perform very well on efficiency. For a long time (until 2014), they were the technologies offering the highest efficiency. There were approached by second-generation technologies in the 2010s. The cost of these technologies is highly dependent on the price of high purity silicon. The price of high purity silicon was quite high until 2011. At that time, an increase in supply led to a decrease in price. Today, silicon-based technologies offer high performance and low cost. The physical properties of silicon as a semiconductors material and their manufacturing methods make cells based on these technologies very heavy and fragile. These two characteristics	**Advantages** • Efficiency • Cost (dependent on silicon) **Disadvantages** • Weight • Flexibility

	limit the deployability of silicon-based technologies The physical properties of silicon create some limitations for these technologies. T and make silicon-based technologies suitable only in certain market segments.	
Second-generation	Second-generation technologies are based on new semiconductor compounds and manufacturing methods. The semiconductor compound is deposited or printed on thin film of plastic or metal. This makes second-generation technologies extremely thin and flexible. Thus, they are a lighter and more versatile option than silicon-based technology. Yet, they offer slightly worse performance in terms of lifetime as some of these compounds degrade faster. For much of the industry history, these technologies represented a low cost alternative to silicon, especially before the drop in silicon's price that occurred in 2011. This was counterbalanced by lower efficiencies until 2014. On average, nowadays second-generation technologies are considered a promising option only in some market segments that are still in their infancy.	**Advantages** • Weight • Flexibility • Lower cost **Disadvantages** • Lower lifetime (degradation) • Efficiency (very poor until 2014)
Third-generation	Third-generation technologies rely on new classes of semiconductor materials, such as Copper Zinc Tin Sulfide (CZTS), polymers or organic material, that are environmentally friendly and abundant. These technologies are lacking in terms of efficiency but promise to be the lowest-cost technologies in solar PV (if large-scale manufacturing can be reached). These technologies do extremely well on transparency and flexibility, and offer incredible design versatility (e.g. the color can be chosen).	**Advantages** • Transparency • Weight • Flexibility • Low-cost (potential) **Disadvantages** • Lifetime (degradation) • Efficiency

Table 8-4 Coding scheme of technology-market fit

Technology-Market Pair	Fit	Technology-Market Pair	Fit	Technology-Market Pair	Fit
First gen. -Residential rooftop systems	High	Second gen. -Residential rooftop systems	Partial	Third gen. -Residential rooftop systems	Low
First gen. -Commercial rooftop systems	High	Second gen. -Commercial rooftop systems	Partial	Third gen. -Commercial rooftop systems	Low
First gen. -Ground-mounted systems	High	Second gen. -Ground-mounted systems	Low	Third gen. -Ground-mounted systems	Low
First gen. -Solar tiles	Partial	Second gen. -Solar tiles	High	Third gen. -Solar tiles	Low
First gen. -Building façade	Low	Second gen. -Building façade	High	Third gen. -Building façade	Low
First gen. -Solar glass	Low	Second gen. -Solar glass	Partial	Third gen. -Solar glass	High
First gen. -Solar floor	Partial	Second gen. -Solar floor	High	Third gen. -Solar floor	Low
First gen. -Off-grid	Partial	Second gen. -Off-grid	High	Third gen. -Off-grid	Partial
First gen. -Canopy/shelters	Partial	Second gen. -Canopy/shelters	High	Third gen. -Canopy/shelters	Partial
First gen. -Military	Partial	Second gen. -Military	High	Third gen. -Military	Partial
First gen. -Consumer electronics	Low	Second gen. -Consumer electronics	Partial	Third gen. -Consumer electronics	High
First gen. -Indoor applications	Low	Second gen. -Indoor applications	Partial	Third gen. -Indoor applications	High
First gen. -Chargers	Low	Second gen. -Chargers	Partial	Third gen. -Chargers	High
First gen. -Vehicles	Partial	Second gen. -Vehicles	High	Third gen. -Vehicles	Partial
First gen. -Aerospace	Low	Second gen. -Aerospace	High	Third gen. -Aerospace	Partial
First gen. -Solar fabric	Low	Second gen. -Solar fabric	Partial	Third gen. -Solar fabric	High
First gen. -Lights/lamps	Partial	Second gen. -Lights/lamps	High	Third gen. -Lights/lamps	Partial
First gen. -Sails	Low	Second gen. -Sails	Partial	Third gen. -Sails	High
First gen. -Pumps	Partial	Second gen. -Pumps	High	Third gen. -Pumps	Partial