SHAPING AN INDUSTRY'S VALUE PROPOSITION AS A STRATEGIC RESPONSE TO AN UNATTAINABLE SUBSTITUTION THRESHOLD

ABSTRACT

Technology substitution is a central process in the technology evolution literature, yet our understanding remains largely limited to incumbent firms' responses and outcomes. For example, existing studies emphasize how incumbents may impede substitution by improving the performance of incumbent technologies such that the substitution threshold shifts upward and becomes unattainable for firms developing new technologies. While such strategic actions by incumbents obstruct the substitution process, surprisingly little is known about the strategic responses available to firms developing new technologies.

We address this lacuna by theorizing shaping as a strategic response available to firms developing new technologies when facing an upward shift in the substitution threshold. Integrating research on technology substitution with the literature on endogenous shaping, we argue that when the substitution threshold becomes unattainable, these firms may attempt to shape the industry's value proposition by altering consumers' shared beliefs about the product's utility and, consequently, about which technological attributes are valuable. This, in turn, redefines the substitution threshold itself, making it attainable again.

We empirically examine our theorization through an in-depth study of the photovoltaic cell industry, combining qualitative and quantitative data. Our analysis reveals a strategic shift among startups following a sharp upward shift in the substitution threshold around 2010, as firms developing new technologies shifted their strategy toward shaping the industry's value proposition.

This study expands the repertoire of strategic responses available to new technology firms during substitution processes and advances research on endogenous shaping by identifying conditions under which shaping emerges and how the process unfolds.

1. Introduction

The substitution of an incumbent technology by a new one is central to models of technology evolution (Nelson & Winter, 1982; Dosi, 1982; Tushman & Anderson, 1986). Existing research has examined technology substitution primarily from the perspective of the firms developing the incumbent technology, highlighting the disruptive effect such processes may have on competitive dynamics (Christensen & Bower, 1996; Chu et al., 2025). According to this research, these firms may seek to adapt to the future business environment in which the new technology substitutes the incumbent technology they develop (Bigelow et al., 2019; Cohen & Tripsas, 2018; Rafaelli, 2019; Tripsas & Gavetti, 2000; Wu et al., 2014). However, these firms also often seek to impede the substitution process by extending the incumbent technology through performance improvements (Furr & Snow, 2024; Henderson, 1995). Improving the incumbent technology's performance may undermine the new technology's potential to substitute the incumbent technology by shifting the substitution threshold—the net utility requirements of consumers of the incumbent technology that need to be met for the new technology to become competitive (Adner, 2002)—upward so that it becomes unattainable (Furr & Snow, 2024). While these strategies and their consequences for the incumbent firms have received extensive attention, surprisingly little research has focused on the strategic responses of firms developing new technologies in the face of the incumbent firms' actions.

While prior research established the indubitable phenomenological importance of upward shifts in the substitution threshold following the incumbent technology's performance improvements (e.g., Henderson, 1995; Tripsas, 2008; Utterback, 1996), strategic management research has yet to systematically examine how firms developing the new technology respond to them. Existing models of technology evolution offer only a restricted repertoire of strategic responses (Furr & Snow, 2024; Malerba et al., 2007). When faced with a dynamically upward-shifting substitution threshold that becomes unattainable, firms developing the new technology are presented with limited options: redeploying resources to other markets or becoming obsolete.

By contrast, we submit that the literature on endogenous shaping provides insights that augment the repertoire of strategic responses for these firms.

In our current study, we connect the research on technology substitution to the literature on endogenous shaping (Cattani et al., 2018; Rindova & Courtney, 2020; Vinokurova, 2019). Specifically, we submit firms' shaping of the industry's value proposition as a strategic response when an upward shifting substitution threshold becomes unattainable. An industry's value proposition refers to the collective utility the industry provides to consumers. Hence, when firms enact a shaping strategy in response to an unattainable substitution threshold, they no longer seek to attend to the established net utility requirements (substitution threshold). Instead, they now intend to shape those requirements to align with the attributes on which the new technology outperforms the incumbent. To shape the industry's value proposition, they enact strategies oriented toward altering consumers' shared beliefs about that proposition, such that the new technology's distinctive attributes that initially were not valued in the targeted industry now become valued. In doing so successfully, the substitution threshold is altered and becomes attainable again. Adjusting the product attributes that define consumers' net utility threshold implies altering the socio-cognitive dimensions of the demand function of the payoff structure, which is what Gavetti and colleagues define as endogenous shaping (Gavetti et al., 2017; Helfat, 2021).

We empirically examine shaping as a strategic response in the photovoltaic (PV) cell industry by conducting an in-depth analysis of the strategic responses of startups developing new technologies when performance improvements of the incumbent technology shifted the substitution threshold upward. These startups are *de novo* firms founded as new entrants in the PV cell industry. Such an in-depth analysis allows researchers to provide a contextualized explanation and interpretation of the phenomenon of interest (Argyres et al., 2020). Using both quantitative and qualitative data, our empirical analysis shows a strategic shift by startups when they face a sudden upward shift in the substitution threshold around 2010. It shows how startups shift toward challenging the silicon-based PV cells (incumbent technology) by shaping the industry’s value proposition. For example, our quantitative text analysis of startups' webpages illustrates the post-shift change in value proposition pursued by startups developing the new technologies (who were at a disadvantage after the shift).

Our study contributes to the literature on technology substitution. First, prior research has paid relatively little attention to the strategic responses available to the developers of new technologies when facing adverse outcomes of incumbents’ actions during the substitution process. Our detailed and rich analysis of shaping in the context of an upward shift in the substitution threshold is informative for future theorizing on the repertoire of strategic responses to the incumbent firms’ actions and the endogenous processes altering the substitution threshold. By analyzing a case where the developers of new technologies face adverse events, we move toward a more comprehensive understanding of the technology substitution process. Second, we contribute to the emerging stream of research on endogenous shaping. The extant work on shaping has established it as a strategy actively pursued by firms (Cattani et al., 2018; Gavetti et al., 2017; Jacobs & Lee, 2025; Rindova & Courtney, 2020), yet relatively little is known about the drivers, mechanisms, and consequences of shaping. By theorizing and empirically analyzing firms’ shaping as a strategic response during the technology substitution process, we shed light on the conditions under which shaping emerges as a strategic response and how the process unfolds.

The paper continues as follows. In the next section, we introduce our theorization on shaping as a strategic response to an upward shift in the substitution threshold. Next, in section 3, we explain our empirical research method and the data used. In section 4, we develop an in-depth case study of the PV cell industry, illustrating the shift from a traditional technology substitution process (section 4.1) to a process characterized by shaping as a strategic response (section 4.3) to a dynamic shift in the substitution threshold, which is discussed in section 4.2. We also explore the role of other actors in the shaping process (section 4.4) and the drivers of shaping as a strategic response (section 4.5). In the last section, we present our study’s conclusions.

2. Theory

Central to this paper's conceptualization of technology substitution is the question of how firms developing new technologies respond when incumbents' actions undermine the new technology's competitive potential. Extant research on technology substitution has largely approached technology substitution through the lens of the "innovator's dilemma". By focusing on the incumbent technology threatened by displacement, this research examines whether and how incumbents respond to the emergence of potential substitutes (e.g., Christensen & Bower, 1996; Chu et al., 2025; Furr & Snow, 2024; Tripsas & Gavetti, 2000; Roy et al., 2018), and the outcomes of these "counteroffensive strategies" (Cohen & Tripsas, 2018; Furr & Snow, 2015 & 2024; Wu et al., 2014). Incumbents may choose to adopt the new technology (Christensen & Bower, 1996; Tushman & Anderson, 1986), yet uncertainty about whether and when the new technology will meet the substitution threshold may lead incumbents toward hybrid approaches that bridge between the old and the new technologies (Cohen & Tripsas, 2018; Furr & Snow, 2015 & 2024). As another response, scholars have shown that incumbent technologies notably improved their performance when being challenged (Henderson, 1995; Adner & Kapoor, 2016). Such improvements have been observed in settings such as typesetting (Tripsas, 2008), semiconductor equipment (Henderson, 1995), and even ice harvesting (Utterback, 1996). More recent observations suggest that, internal combustion engines improved their efficiency as electric vehicles emerged as a viable substitute (Furr & Snow, 2024). These improvements not only extend the revenue generated from incumbents' existing assets but may also threaten the substitution process itself.

Insert Figure 1 here

The logic for this threat is depicted in Figure 1. Classic models of technology substitution posit that a new, initially inferior technology becomes competitive once it reaches the mainstream consumer's net utility threshold (NUT in Figure 1), i.e., the substitution threshold. This threshold entails a trade-off between the performance of the product and the product's price

(Adner, 2002). This substitution threshold might be, but is not always, at the performance level of the incumbent technology (Malerba et al., 2007). When consumers experience diminishing marginal utility from further performance improvements, incumbents may “oversupply” performance at higher cost, which results in a substitution threshold that lies below the incumbents’ performance level (Christensen & Bower, 1996). In either case, the new technology gains competitiveness when it meets this substitution threshold. Substitution occurs either because the new technology outperforms the incumbents on attributes valued by mainstream consumers (Tushman & Anderson, 1986; Utterback, 1996) or, if it underperforms on those attributes, because it provides alternative features that consumers increasingly value once the threshold is met (Christensen & Bower, 1996; Adner, 2002). In Figure 1, a new technology introduced at t_0 is expected to improve performance over time and reach the substitution threshold by time t_2. However, as noted above, this threshold may shift upward if the incumbent technology improves its performance, moving from NUT to NUT_{ps}. As illustrated by the trajectory of the new technology, once the shift in the substitution threshold (NUT) materializes at t_1, this threshold (NUT_{ps}) becomes unattainable for the new technology.

While extant research has extensively examined the responses of incumbents when challenged by new technologies, including the strategic extension of the old technology through performance improvements, the responses to these actions by firms developing the new technology remain underexplored in the literature. Given that upward shifts in substitution thresholds are not uncommon and may impede substitution (Furr & Snow, 2024), it is surprising that a repertoire of strategic responses for firms developing new technologies is absent from the technology substitution literature. For these firms, an unattainable substitution threshold seems to inevitably lead to their demise (Furr & Snow, 2024; Malerba et al., 2007). While the entrepreneurship literature has examined a wide range of strategies for potential disruptors, from collaborating with incumbents (e.g., Gans & Stern, 2000; Gans et al., 2021) to avoiding competition through the strategic definition of market segments (Santos & Eisenhardt, 2009), the issue of the emergence of an unattainable substitution threshold has not yet been addressed.

Looking beyond this research, we identify a few strategic options for response as we consider the upward shift of the substitution threshold as an adverse technological event. Strategy scholars explored how, in response to innovation shocks, firms adjust their market position through imitation, exit, or niche retrenchment (Argyres et al., 2015 & 2019; Bigelow, 2018). Their choice among these options depends on their comparative adjustment, transaction, and opportunity costs. These factors have also been shown to influence complementors' responses to platform-level changes (Argyres et al., 2025). Similarly, research on the dominant design established exit, repositioning, or imitation as strategic responses for those firms developing technologies that did not become dominant (Bayus & Agarwal, 2017; Eggers, 2012). Hence, for firms developing a new technology suddenly facing an unattainable substitution threshold, it seems that to survive, they can position their technology in a niche market or pivot it toward another industry (Argyres et al., 2015), eventually enhancing it with another functionality (cf. Dew & Sarasvathy, 2016). To compete for the mainstream consumer, however, they'll have to imitate the incumbent technology (cf. Bayus & Agarwal, 2007; Eggers, 2012). If they continue in the main market offering the new technology, they likely starve out due to resource constraints, as mainstream consumers will continue with the incumbent technology and investors won't see a viable path forward for the new technology (Furr & Snow, 2024; Malerba et al., 2007).

The deterministic characterization of the industry environment in these studies unsurprisingly yields mostly adaptive responses. Just as firms facing an innovation shock or the emergence of a dominant technology are expected to adapt to that new, exogenously determined industry environment, firms developing a new technology are similarly restricted to adaptation when the substitution threshold is treated as exogenously given.

Not recognized in this characterization, however, is that the substitution threshold is not exogenous to the firms subjected to it. The emerging theories on endogenous shaping by firms emphasize that rather than adapting to their external environment, firms may enact strategies that prompt efforts to redefine 'the rules of the game' (Gavetti et al., 2017; Rindova & Courtney, 2020). Helfat (2021) defined endogenous shaping as actions by firms that alter the industry payoff structure for all actors subject to it. This payoff structure is composed of a supply and demand function. Hence, firms can employ strategies to shape these functions. Particularly during periods of change, such as in cases of industry-level technological shifts, this type of strategy may be conducive (Furr & Eisenhardt, 2021; Rindova & Courtney, 2020). While firms may resort to non-market strategies enabling favorable regulatory institutions (Gao & McDonald, 2022; Uzunca et al., 2018), they may also focus on changing other actors' competitive sensemaking, as shared beliefs that govern the industry (Cattani et al., 2018; Cornelissen et al., 2015; Vinokurova, 2019). For example, firms can design and enact shaping strategies oriented at altering other actors' knowledge and beliefs about the industry's value proposition to align with their vision for the future (Cattani et al., 2018; Dew & Sarasvathy, 2016). As the shared beliefs about the value proposition prevalent in the industry are altered, the relevant attributes for evaluating a product's performance and their relative weight in the payoff structure also alter (Khaire, 2014; Khaire & Wadhani, 2010). This implies that firms can design and enact strategies to alter an industry's substitution threshold by reshaping the attributes considered and their relative importance in the mainstream consumers' net utility function (cf. Vinokurova, 2019).

Hence, the literature on endogenous shaping suggests that when facing an adverse shock, such as an upward shift in the substitution threshold, firms developing the new technology may be prompted to pursue a strategic response aimed at altering this very threshold. These firms' strategic response is aimed at altering the shared beliefs regarding the value the industry creates for the consumer, which ultimately shapes the demand function that defines firms' economic rewards (Helfat, 2021). The alternative value proposition aligns with the shaping firms' vision for the industry's future—one that cannot be realized under the prevailing beliefs. Moreover, this alternative value proposition leverages technology-specific attributes and applications. Acknowledging that shared beliefs tend to ossify over time, shaping firms may take advantage of the aftermath of the shift in the substitution threshold, when resistance to change is weaker, to advocate for and advance an alternative value proposition (cf. Greenwood & Hinings, 1996).

To enrich our understanding of the potential strategic responses by firms developing new technologies during the process of technology substitution, we connect the literature on technology substitution to the research on endogenous shaping. As such, we provide a more comprehensive view of the complex process of technology substitution. We argue that the sudden impossibility of attaining the substitution threshold prompts a reconsideration about chasing this threshold. Once this threshold becomes unattainable, firms developing new technologies may begin to emphasize different product attributes that support alternative applications and, in essence, a different value proposition for the industry. To displace the incumbent technology, these firms aim to persuade mainstream consumers of the value proposition they propose, made possible by the distinct attributes of the new technology they develop. As such, they aim to alter the socio-cognitive dimensions that define the substitution threshold and their relative importance, herewith also altering the demand function of the industry's payoff structure (Helfat, 2021; Vinokurova, 2019).

Adding shaping to the repertoire of strategic responses requires us to consider who is likely to employ shaping. For startups developing new technologies, such an upward shift not only entails economic losses but also represents an existential risk to their viability and their imagined future for the industry. The existential risk is particularly acute in industries oriented towards addressing grand societal challenges, where startups often pursue technologies envisioned as solutions to these challenges. In such contexts, a shift in the substitution threshold that locks the industry in an inferior incumbent technology precludes the perceived feasibility of addressing the grand challenges. When technology lock-in precludes potential solutions from addressing the grand challenges, the challenges at stake will remain unresolved. The startups that view the current shared beliefs as misaligned with the most promising solution may seek to contest and replace the shared beliefs. In doing so, the startups may attempt to shape the industry's value proposition to the advantage of their technologies, not solely for economic gains, but because they view their new technologies as essential to addressing a grand societal challenge. In such contexts, shaping as a strategic response becomes a means for aligning the shared beliefs with both the startups' envisioned future and their perceived responsibility to help solve a grand challenge.

To understand the process of shaping an industry's value proposition as a strategic response to an upward shift in the substitution threshold, in the next section, we conduct an in-depth analysis of how startups in the PV cell industry enacted a strategy to shape the industry's value proposition.

3. Research Method and Data

In line with other studies that examined firms' responses to changes in their technological and market environment (e.g., Cattani et al., 2024; Danneels, 2011; Engler et al., 2020; Malerba et al., 2008), our research method employed a case study approach to examine how startups responded to an unexpected upward shift of the substitution threshold they were trying to achieve. This method is well-suited to leverage both quantitative and qualitative data toward an in-depth understanding of the examined process (Argyres et al., 2020), while also being a useful tool for examining evolutionary processes because they provide context-specific manifestations of the phenomena under investigation (Nelson, 1994). Accordingly, we conducted a detailed historical analysis of the changes in the strategic approach by startups developing new technologies in the PV cell industry that were poised to replace the incumbent technology. We place the shaping strategy enacted by some of these startups in the context where industrial policies shifted the substitution threshold. We shed light on both the period prior to and after the shift to demonstrate how the startups' strategic response to the upward shifting substitution threshold unfolded over time. To capture this information "in a large-scale quantitative empirical study" would not be possible (Maritan & Lee, 2017: 2145). Through a rich and detailed case study, rather than providing a testing of hypotheses, we aim to illustrate and ground shaping as a strategic response to an unattainable substitution threshold in a real-world historical context.

3.1 Operationalizing Shaping: Communication and Resource Allocation

The enactment of a shaping strategy requires actions oriented at convincing industry actors about the desirability and feasibility of the imagined future (Cattani et al., 2018; Pontikes & Rindova, 2020; Rindova & Martins, 2022). When convinced that the shaper's imagined future will be realized, industry actors will update their beliefs and resource allocation in alignment with that future (Jacobs & Lee, 2025). A widespread updating in that sense will result in novel shared beliefs about the (future) industry environment (Luksha, 2008).

To capture the actions oriented toward updating the shared beliefs about an industry's value proposition, we build upon institutional entrepreneurship research, which also studies agency (Battilana et al., 2009). While institutional entrepreneurship literature focuses on actions by which new institutions and organizational forms are legitimized (Santos & Eisenhardt, 2009), we focus on firms shaping the competitive environment in which they operate. Consistent with institutional entrepreneurship research, the research on endogenous shaping emphasizes sensegiving and the role of *storytelling* (Cattani et al., 2018; Pontikes & Rindova, 2020).

The research on institutional entrepreneurship has long recognized the role of language (Battilana et al., 2009; Cornelissen et al., 2015), which is increasingly viewed as performative—focused on *sensegiving*, or shaping how others interpret reality (Cornelissen et al., 2015; Harmon et al., 2015; Suddaby & Greenwood, 2005; Ocasio et al., 2015). Through deliberate discursive strategies, firms have influenced how customers assess novel products and technologies (Cattani et al., 2018; Kahl & Grodal, 2016), shaped how investors evaluate emerging industries (Harmon et al., 2023), and altered perceptions of industry boundaries (Grodal, 2018). Overall, the body of work that examined the link between communication, cognition, and cognitive logics established a clear link among firms' communication efforts, industry actors' shared beliefs, and institutional change, with sensegiving emerging as a key mechanism.[1] The importance of language in this process is described by Cornelissen et al. (2015: 13) as follows: "*Language has a performative role in that its use pragmatically affects actors in their thoughts and behaviors, which also means that language in its use bears the brunt of initiating broader cognitive change at the level of an institutional field.*"

Firms' communication is thus considered to guide others' sensemaking and interpretation of the firms' actions (Phillips et al., 2004; Rindova & Courtney, 2020). However, because communication is often designed to persuade, it can become decoupled from actual practices (Favaron & Di Stefano, 2025; Ocasio et al., 2015). This is, for example, seen in cases of 'greenwashing' (Kim & Lyon, 2015; Wu et al., 2020). Therefore, it has been argued that a successful shaping strategy must go beyond communicative efforts to convince others and include activities that are consistent with the imagined future being promoted (Pontikes & Rindova, 2020; Rindova & Courtney, 2020). The shapers' *storytelling* to convince others to adhere to their imagined future needs to be accompanied by supporting resource allocation, such as committing investments in technology improvements. In some cases, resource allocation may also be necessary to demonstrate the plausibility of the imagined industry trajectory (cf. Jacobs & Lee, 2025). Ultimately, communication (as a foundational part of storytelling) and resource allocation are not substitutes but interdependent components of a shaping strategy. Therefore, our operationalization of a shaping strategy captures the shapers' communication and resource allocation.

3.2 Data

[1] While it is recognized that the shared beliefs among the diverse industry actors often are the result of a continuous process of interactions among these actors, the performative character of language is considered crucial as it reflects the intentions of the actors involved in these interactions.

To avoid bias and increase confidence in the empirical findings, our historically grounded study triangulates different types of data from multiple data sources (Kipping & Üsdiken, 2014). Our data draws on more than 2500 primary and secondary source documents collected between 2019 and 2024. We also conducted 11 semi-structured interviews with select current and former industry participants who were involved in the development of the PV cell industry and witnessed the environmental shock to the industry.[2] These sources were complemented with quantitative data on firms' patenting activities, venture capital investment data on the funding startups received, as well as data on government grants for the development of PV cells.

To identify startups operating in the PV cell industry, we searched the World Directory of Renewable Energy Suppliers and Services,[3] the Cleantech i3 Platform, Crunchbase, ENF Solar, the International Energy Agency, and industry literature (e.g., Wolfe, 2018). Overall, we identified 329 firms as active in the PV cell industry between 1954 and 2020. Of these, 243 were categorized as startups based on archival data, funding information, and firms' patenting activity.

As discussed above, a shaping strategy is operationalized with two components: startups' communication, captured through their historical webpages, and their resource allocation to technology development, captured through their patenting patterns over time. To establish the change in communication over time by startups, we analyzed startups' historical web pages. Using the Wayback Machine, we captured the home pages of PV cell startups between 2000 and 2020 (one capture per year). We start our observations in 2000, which is several years ahead of the shift in the substitution threshold, allowing us to establish a baseline. Moreover, prior to 2000, the internet was not ubiquitous, with web browsers and navigators only emerging in the late 1990s. Broadband internet became more readily available in the early 2000s, solidifying the internet as a staple for many users and urging more firms to develop a web page. We were able to capture the web pages of 189 startups, with an average of 6.74 years of pages per startup.[4]

[2] Profiles of the interviewees are available in the online appendix to this manuscript.
[3] This printed directory was published from 1995 and 2002.
[4] Minimum observations: 1; Maximum observations: 21.

We collected patent data on the global PV cell industry using the Derwent World Patent Index.[5] More specifically, for the period 1976-2020, we searched all patents granted by the U.S. Patent and Trademark Office (USPTO)[6] with claims related to PV electricity generation. To avoid including patents that cover innovations related to other components of a solar energy system (e.g., inverters), we developed a list of keywords for each of the different PV cell technologies based on a detailed study of the industry literature and subsequent validation with an expert in PV cell technologies. By analyzing the incidence of these keywords in the full text of the patent, we were able to identify patents related to PV cell technologies and map them to their corresponding PV cell technology. This process resulted in the identification of 8398 patents assigned to firms.[7] We matched the assignees of these patents to the startups present in the population of firms active in the PV cell industry. As such, 898 patents were identified as patents created by firms founded within the boundaries of the PV cell industry.

Information on venture capital funding for PV cell startups was collected from Crunchbase, Cleantech i3 Platform, and VentureXpert. Using these databases, we mapped the funding rounds and their respective dates, together with the known investors for each of the startups in our sample. Moreover, we could identify whether these investors were financial or corporate venture capital investors.

More broadly, we collected an extensive and diverse set of industry documents and publications that cover the terrestrial PV cell industry from its inception in the mid-70s until 2022. These documents helped us trace the industry's evolution, with special attention to the activities around 2010, when the upward shift in the substitution threshold occurred, and startups faced a new reality in which competing on cost and efficiency favored silicon-based PV cells used by solar panel manufacturers.

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[5] We used the technological classes listed on DWPI, Electrical Patents Index (EPI)–Part 3, subject "Solar cell".
[6] Prior studies (Almeida, 1996; Lahiri & Narayanan, 2013) have established that successful patent applications filed with the USPTO are representative of global inventive activities in settings in which the U.S. plays a major role.
[7] To identify patents assigned to firms, we used the patent's assignee type in Patentsview, which distinguishes between patents issued to "organizations" and those issued to individuals and government institutions. By examining the names of patents' assignees, we were able to separate those issued to universities and research institutes.

4. Shaping the Value Proposition of the PV Cell Industry as a Strategic Response to a Dynamic Substitution Threshold

Our empirical analysis focuses on the terrestrial PV cell industry. The PV cell industry provides an ideal setting to demonstrate how startups try to reshape the industry's value proposition when facing an upward shift in the substitution threshold that made chasing the threshold an unattainable goal. The industry was shocked by a sudden and unanticipated surge of demand for PV cells following government subsidies and a subsequent precipitous drop in the costs of silicon-based PV cells due to oversupply around 2010 (Furr & Kapoor, 2018; Hannah & Eisenhardt, 2018; Hart, 2020). As we discuss in detail below, the shock triggered by government policies resulted in silicon-based PV cells that were so cheap that new technologies outperforming them on their price/performance trade-off became not feasible. Prior to this shift, there existed an understanding among industry actors that the substitution of silicon-based PV cells (the first generation of PV cell technologies) was a matter of time, given the promising the cost-efficiency potential of the newer generations of technologies as well as their additional attributes that would enable 'solar everywhere' (e.g., integrated into buildings, vehicles, roadways, or fabrics) (Jacobs & Lee, 2025). By 2010, these newer technologies that had the potential to unseat silicon-based PV cells on cost and efficiency no longer had a chance of catching up to the new threshold. While many startups exited the industry after the substitution threshold's upward shift, multiple startups in the PV cell industry developing second and third-generation technologies employed strategies to shape the PV cell industry toward a different value proposition. For many, a lock-in with silicon-based PV cells would mean not only an economic loss but also a societal loss because the solar industry under lock-in will not be able to deliver its maximum contribution to address the grand challenge of climate change (Hart, 2020). This relatively recent and currently ongoing phenomenon presents us with an empirical context to study startups' responses when facing an unattainable substitution threshold.

4.1. The Technology Substitution Process Prior to the Upward Shift

The discovery of the photovoltaic effect, that is, the conversion of sunlight into an electric current, opened the possibility for electricity generation in a way that departs substantially from generating electricity with fossil fuels (Chase, 2019). Although the first PV cell was presented in 1954 by the Bell Laboratories, it was the oil crises of the 1970s that sparked real interest in the potential of PV cells for residential and commercial use (Nemet, 2019). The earliest cells, like the one from the Bell Laboratories, used silicon semiconductors. The silicon semiconductor wafers make silicon PV cells rigid, heavy, and non-transparent, restricting their use mainly in stationary solar panels (Jean et al., 2015).

In the early 1980s, a second generation of PV cell technologies was introduced to compete with silicon cells: thin-film cells (Kalthaus, 2019). Thin-film cells use different types of semiconductors, including amorphous silicon, Copper Indium (Gallium) diSelenide, and Cadmium Telluride (Wolfe, 2018). A third generation of PV cell technologies emerged in the 1990s and 2000s as organic cells, dye-sensitized cells, Perovskite cells, and quantum dot cells were introduced (Jean et al., 2015). The second and third-generation technologies had a cost-efficiency potential to outcompete silicon PV cells (Hart, 2020, Wolfe, 2018). At the onset of the 21st century, industry insiders generally believed that the demand for second- and third-generation cells would take off once they reached efficient scaling. Whereas the second and third generations have cost efficiency advantages in the preparation of input materials, the preparation that is required in the first generation is costly and highly energy-intensive (WEF, 2015). As one of our interviewees stated: "*We dealt in silicon cells at the time, but we concluded that the future was going to be thin-film cells because it seemed inevitable that if you used a 1,000th as much material, they were going to be cheaper… I did project that thin-films would become the major technology a long time before now…*"

As shown in Figure 2, the potential of second- and third-generation technologies to outcompete the first generation in the long run made them attractive for venture capital investors.

The interest of these investors in startups developing second- and third-generation technologies confirms their perceived economic viability in the pre-shift period, where PV cells were considered a commodity, and the industry thus was guided by a cost-efficiency logic.

Insert Figure 2 here

The introduction of second and third-generation PV cell technologies spawned a path toward flexible, lightweight, ultra-thin, and transparent PV cells. In turn, these attributes forged opportunities for applications that moved cell functions beyond the production of electricity (Guerra et al., 2025; Jacobs & Lee, 2025). Industry players started to think of a much broader deployment of PV cells, which would increase their contribution to reducing carbon emissions. For example, in 2002, it was calculated that the availability of building-integrated photovoltaics would increase by 35 percent the surfaces on which PV electricity could be generated (IEA, 2002). Covering only the south side of buildings in Germany with PV cells that reach a 10 percent conversion rate would be enough to provide the whole country with the electricity it requires (Oliver & Jackson, 1999). Industry players were hopeful and looking forward to the new applications that were just developing (Chris Cording, director of Solar Development at AFG Glass, cited in NREL, 2003: 11):

> *Photovoltaics is a significant part of our current business and is growing as the solar-electric industry expands in response to the demand for its products and services. This is especially true with the impacts of the building-integrated photovoltaics and architectural glass markets that are just beginning.*

Overall, the potential of these types of cells beyond stationary solar panels made many adhere to the vision that the PV cell industry would evolve into ‘solar everywhere’ (for a detailed description of the emergence of this vision, see Jacobs & Lee, 2025).

The realization of this vision, however, depended on the new technologies achieving the same or better cost-efficiency performance as silicon-based PV cells because silicon cells were setting the substitution threshold. Accordingly, the new generations of technology oriented their investments towards lowering production costs and improving efficiency. While the increasing awareness about the future competitive importance of their other attributes led to gradual increases in resource allocation to developing these attributes (Jacobs & Lee, 2025), as we discuss in detail below (see section 4.3), startups strategically promoted the cost and efficiency of their new technologies to encourage adoption from solar panel manufacturers. This focus on cost and efficiency aligns with the traditional models of technology substitution.

4.2. The Upward Shift of the Substitution Threshold

The industry changed dramatically, however, when governments took on the role of 'landscape shapers' through their industry policies (cf. Li & Csaszar, 2019). In 2004, the German government introduced generous feed-in tariffs (Sandén, 2005; Georgallis & Duran, 2017). These tariffs guaranteed compensation to owners of solar panels when sending 'excess' energy to the grid. The introduction of feed-in tariffs in Germany, and soon after in many European countries, made the demand for PV cells boom (Georgallis, Dowell, & Durand, 2019; Georgallis & Durand, 2017). The sales take-off created by this increase in demand, however, was mostly channeled towards silicon-based cells, which presented the best cost-efficiency balance to customers (Chase, 2019) and a more mature ecosystem (Guerra & Agarwal, 2024) at the time. Moreover, the increase in demand for solar panels attracted Chinese manufacturers. These manufacturers adopted the technology they were most familiar with: silicon-based PV cells.[8] With the help of mainly German equipment manufacturers, the Chinese PV cell industry evolved rapidly to become a manufacturing powerhouse (Sivaram, 2018). The support from the Chinese government to their domestic silicon-based PV cell industry led these companies to deliver excessive amounts of PV cells at ever-lowering prices (Hart, 2020). This 'subsidized' scaling of the Chinese PV cell industry resulted in a precipitous price drop for silicon-based PV cells (Chase, 2019). At the same time, thin-film technologies struggled to create an integrated

[8] Out of the 55 Chinese companies entering the PV cell industry, 48 (87%) entered with silicon-based PV cells.

ecosystem needed to scale their manufacturing, resulting in their failure to benefit from the sales take-off (for an in-depth analysis of thin-film's failure and silicon's success, see Guerra & Agarwal, 2024). In general, the alternatives to silicon-based PV cells were unable to compete with the cheap Chinese silicon-based PV cells.

The shock in demand and supply altered the substitution process in a sudden and unanticipated way. Whereas prior to the shock, second- and third-generation technologies were viable due to their projected catch-up in cost-efficiency improvement, this potential dissipated after the shock. Initially, there was still some belief that second- and third-generation technologies would be able to catch up and even outperform, as expressed by one of our interviewees: '*There was a lot of argument, and there still is probably that this [thin films, sic] can be inherently cheaper than silicon, and that was certainly in the 2013-2014-2015 timeframe when these [thin film companies, sic] were all acquired… So, the belief in thin films was still high.'* However, many firms developing second- and third-generation technologies exited in the direct aftermath of the shift (Furr & Kapoor, 2018; Hannah & Eisenhardt, 2018). Observing the survival of firms still active in 2009, as shown in Figure 3, we notice a decline in the number of survivors across technology generations. The steepest decline can be observed in the second generation of technologies, which lost 46 of 80 firms (57.50 %) between 2010 and 2015, relative to 40 out of 127 firms (32.25%) in the first generation, and 8 out of 23 firms (34.78%) in the third generation. Analyzing the entry of firms by observing firms that started commercializing PV cells (cf. Helfat & Lieberman, 2002; Kapoor & Furr, 2015), we observe a downward slope around the same time (Figure 4). These observations of major reductions in survival and entry indicate adverse changes in the industry's competitive environment for startups developing the newer generations of PV cell technologies.

Insert Figures 3 & 4 here

In the next section, we examine how surviving and new startups responded to this new reality.

4.3. Startups' Strategic Response to an Unattainable Substitution Threshold

As cost-competition intensified in the solar panel market, startups developing second- and third-generation technologies realized that they had to change their strategy:

> *And one thing that we saw was really for broader adoption. Not everybody really loves the way that the traditional solar panels look, and they're kind of limited to where you can put them. And that's the reason we saw this opportunity in the market that if we are able to develop something that solves this aesthetic compromise that people sometimes are making, but often not everybody wants to make, then we can have something that's a potentially better offering that also can continue to deploy solar technology but in a different way where people don't even really think about it…*
>
> *And so that's what became the basis for us and also how we've felt our technology was going to be really differentiated because I think that's another problem when you look at dominant technologies and when they take over the industry, it becomes really hard to differentiate and it almost becomes this commoditized effective race to the bottom who's going to be the cheapest and deployed that way. And especially with what was kind of happening with China, people knew, people started realizing there's no way we can compete on cost.*

Another interviewee expressed a similar strategic approach:

> *Our original plan was head-to-head with silicon and a solar panel, you know PV modules, and do it with a fraction of the cost of silicon and much better energy yield and more useful… We were probably in 2010 focused on just the stationary. It was when we saw that the price was just continuing to plummet that we started to question that… So we were certainly going through this process of, so what if everything we had assumed in our market plan turned out to be wrong, and we aren't ever going to build a flat panel module, what would we do? And actually, when we started uncovering a lot of opportunities and switched almost all of our efforts then away from flat panel into kind of an unusual panel…*

Similarly, another interviewee expressed it as:

> *Once they figured out that they're not going to be competitive in that commodity market, they tried to work on the application. And that was, can we have a differentiated application that would sustain a different price structure? Everybody has tried it. I mean everybody.*

Departing from the prevalent value proposition of PV cells as a commodity, startups sought to alter the cognitive logic toward their new value proposition that entails PV cells' versatility. To shape the prevalent value proposition toward an alternative, startups developing second- and third-generation technologies used public communication that promotes their new value proposition. Their communication emphasizes PV cells' versatility and cell attributes enabling versatility, in contrast to focusing on cells' cost and efficiency. Their emphasis demarcates from the existing logic that aligned with the industry's prevalent value proposition of PV cells as a commodity.

Their pivoting toward a different strategy was not focused on serving niche markets in the existing PV cell industry:

> *We didn't want to create something that was only for a very select part of the market, which was a strategy back to our vision because we wanted this to be equitable, economical, and we weren't really in this to be this slice of a piece of a segment of a market kind of thing.*

Their discourse seeks to shape how others perceive the solar industry by advancing a challenge to the existing logic. Their discourse invites others to imagine a solar industry not as it currently exists, but as it could be reconfigured through the technologies they develop for versatile PV cells. Through their discourse, startups seek to shift the collective understanding and align it with their envisioned trajectory for the industry. Rather than viewing PV cells merely as static generators of electricity, PV cells should be thought of as versatile and providing energy wherever it is needed.

For example, Joel Jean, founder of Swift Solar, states that his startup has developed a product with the potential to greatly increase the use of solar power: a very lightweight, super-efficient, inexpensive, and scalable solar cell (O'Neill, 2020). In a recent public letter (Jean, 2025), he stated that '*Solar is just scratching the surface of its immense potential*' and '*to unlock the full potential of solar energy, we have to look beyond incremental improvements'*. With Swift Solar's Perovskite's technology '*Solar can go where it has never gone before'*. Vladimir Bulovic, a board member of Swift Solar claims that '*the inventions and technological advancements of Swift Solar have the opportunity to revolutionize the format of the solar PV technology'* (O'Neill, 2020). Rayleigh Solar Technology, a US-based startup, promotes its PV cells as thin, lightweight, and low-cost and claims that its cells are the future of solar, while Sunflare (another startup) asserts to bring '*energy where you need it'* with their lightweight, thin, and flexible cells. Similarly, Saule Technologies states on their website that *‘Perovskite technology is for the solar cells of tomorrow’* and that they are *‘reimagining solar power generation’* by *‘creating ultrathin and flexible solar cells’.* Highlighting its type of cells’ differentiating attributes, Solarix, another startup, emphasizes that there are other, aesthetically more appealing ways to create PV electricity than *‘boring black solar panels’* (referring to silicon-based technology). Solarmass’ website opens with ‘*Go solar, do it beautifully*’. At a presentation at the Silicon Valley Energy Summit, Colin Bailie, founder of Tandem PV, asks boldly, ‘*What can solar do for you that it is not already doing?’* (SVES, 2018).

As discussed above, prior research demonstrated how public communication and other forms of persuasion have a formative impact on an industry’s perceived reality by influencing others’ sensemaking (Cornelissen et al., 2015). This sensemaking forms the foundation for the shared beliefs that underpin the cognitive logic guiding interpretation and action in that industry (Cattani et al., 2018; Scott, 2001). Hence, an industry’s value proposition, part of the cognitive logic, is shaped through communication. Several studies that analyzed the communication strategies of firms in the context of institutional entrepreneurship demonstrated that, in addition to the structure of firms’ communication, the linguistic choices or changes to these may trigger and orient institutional change. While these studies often adopted a case-study approach that allows for an in-depth analysis of firms’ linguistic choices and structures (e.g., Grodal, 2018; Kahl & Grodal, 2016; Suddaby & Greenwood, 2005), other studies adopted a quantitative approach that enables the examination of larger sets of text (e.g., Harmon, 2019; Harmon et al., 2023). Harmon et al. (2023), for example, analyzed the effect of public communications (S-1 SEC filings at the time of IPO) by firms with their investors on the adoption of new engagement metrics in the nascent internet industry. The researchers measured the frequency of specific metric labels as an indicator of how central the new engagement metrics were in the firms’ communication about their strategy.

We build upon this quantitative approach to comparatively examine the communication of startups in the period prior to and after the shift in the substitution threshold across technology generations. Considering that the changes in linguistic choices, such as vocabulary, may trigger changes in the cognitive logic of industry actors, a quantitative analysis provides us with further insights into startups' strategy for altering cognitive logics in the aftermath of an upward shift in the substitution threshold.

To analyze startups' communication, we focus on what they present publicly on their web pages. These webpages are considered electronic storefronts through which firms communicate with external stakeholders (Winter, Saunders, & Hart, 2003). As a place where they introduce themselves and their products to potential customers, investors, and other industry actors, webpages are a valuable data source for researchers to infer the communicated value proposition (Chandler, Broberg, & Allison, 2014).

With the assistance of ChatGPT-4o, we evaluated the text that startups presented on their historic web pages over time, following Carlson & Burbano's (2025) instructions for robust data annotation using ChatGPT-4o, a large language AI model. We assigned ChatGPT the task of evaluating the web pages' text and generating two scores for each year we had a web page of the focal startup for the time it was active. The evaluation created two scores: "other attributes" and "versatile applications", each on a scale from zero to ten. A detailed description of how we used ChatGPT, the scoring instructions, and the specific prompts is available in the online appendix of this paper. A high score on "other attributes" suggests a strong emphasis on flexibility, thickness, weight, and transparency as product features. These product features characterize the second and third-generation PV cell technologies and enable the versatile application of these cells (Jacobs & Lee, 2025; Jean et al., 2015). A high score on "versatile applications" suggests a strong emphasis on the cells' diverse applications beyond solar panels. These include building-integrated PV cells (roof, walls, and windows) and PV cells integrated in roadways, vehicles, or fabrics (Guerra et al., 2025; Jacobs & Lee, 2025).

*** Insert Figures 5 & 6, and Table 1 here ***

Analyzing how the scores changed over time in Figures 5 and 6, we observe an increased emphasis on *other attributes* and *versatile applications*, after the upward shift in the substitution threshold around 2010 jeopardized the future substitution of silicon-based PV cells by second- and third-generation technologies. The stronger emphasis is particularly visible in the second- and third-generation technology startups' online communication. Conducting a t-test to compare the scores in the pre- and post-shift period for each technology generation, we find that the score of versatile applications increased significantly in the post-shift period for both the second- (t = 6.12) and the third-generation (t = 4.90) technologies (see Table 1a). These results further confirm the changes in the linguistic choices of these startups, switching to emphasize the versatility of their products instead of a restricted use in rigid solar panels. The emphasis on versatile applications seems to be even stronger for startups developing third-generation technologies. Before the shift, the second and third generations had comparable scores averaged across the startups (t = 1.37). After the shift, the average score was higher for the third generation when compared to the second generation (t = 3.14). By contrast, the score averaged across the startups developing silicon-based PV cells (first technology generation) was persistently lower than that for the second and third generations. Even after 2013, when we notice an increase in the average score of startups developing silicon-based PV cells, the score remains markedly lower compared to the pre-shift scores of the second and third generations. We also compared the scores attributed to new (founded after 2010) and surviving startups (founded before 2010), and found no difference in average scores, indicating that both equally emphasized versatile applications in the post-shift period.

We observe a similar pattern in the scores of other attributes. As shown in Table 1b, an increase in average scores during the post-shift period is observed for each technology generation. However, the increase is bigger for the second (1.58) and third (2.10) generations when compared to the first generation (0.65). Moreover, the average scores of the startups developing first-generation technology are persistently lower than the average scores of the startups developing the second and third generations. Just as for ‘versatile applications’, we verified and found that new and surviving startups equally emphasized other attributes.

Our empirical analysis of the PV cell industry demonstrates that, upon facing an undesirable new reality after an upward shift in the substitution threshold, a group of startups did not merely adapt to this new reality. Instead, they aimed to shape the industry’s value proposition by reorienting the cognitive logic toward PV cells with versatile applications, requiring other attributes than cost and efficiency. They communicated a departure from the industry’s prevalent value proposition, where PV cells were commoditized and intense competition focused narrowly on cost and efficiency. If their communication is successful, the startups establish new shared beliefs around their envisioned value proposition, altering what is economically rewarded in the industry. If unsuccessful, the industry will likely ossify around the cost-efficiency logic and become locked in by an older technology generation. Once this logic is ‘ossified’ there is much less room for agency for change (Menanteau & Lefebvre, 1999). In that case, adaptation, exit, or retrenching into a niche market might be the startups’ only strategic options (cf. Menanteau & Lefebvre, 1999; Tripsas, 2008).

As discussed above, shaping an industry’s value proposition requires more than performative communication; it also demands that the shaper acts in alignment with their communication. This alignment is essential not only to avoid perceptions of decoupling but also to support the ongoing sensemaking processes of other industry actors (Jacobs & Lee, 2025). As actors update their beliefs about the industry, they search for knowledge that substantiates the new value proposition that is being promoted (cf. Rindova & Courtney, 2020). In the PV cell industry, sustained investments in the cells’ flexibility, transparency, weight, and thickness, or product applications, are necessary to ensure that the communicated value proposition is not undermined by a disconnect with technological reality.

*** Insert Figures 7 & 8 here ***

To empirically examine how startups aligned their technological investments with their communicated vision for the future, we examine their patenting, a well-established proxy for resource allocation to innovation (Chang, 2023; Griliches, 1990; McGrath & Nerkar, 2004). We analyzed the title, abstract, and claims of each patent to verify the present of key words that indicate their focus on versatile applications of PV cells [Building-integrated PV cells (integrated in roofs, walls, or windows), PV cells integrated in vehicles, roadways, or fabrics)] or on other attributes than cost and efficiency (cell flexibility, transparency, thickness, or weight). Figures 7 and 8 show that in the period around the shift,[9] patenting activity related to the development of versatile applications (Figure 7) and other attributes (Figure 8) increases, particularly among startups developing second and third-generation technologies. Notably, even the few focused on the first generation have exhibited a moderate rise in innovation efforts toward the development of other attributes. This continued, increased resource allocation toward knowledge development about PV cells' attributes that enable their versatility cannot be explained by a demand by niche consumers. The niche demand was not substantial enough for the startup's survival, because there was no economically viable niche market at that time. Therefore, the continued resource allocation in knowledge development in areas that do not yet yield direct economic returns suggests a strategic intent to construct a knowledge base that backs the shaping discourse. This helps translate startups' communicated commitments into tangible advancements, thereby strengthening the performative power of their communication (cf. Jacobs & Lee, 2025).

Thus far, we have focused our attention on how shaping as a strategic response unfolds in the startups' own communication and resource allocation. However, the mobilization of investors, government, and complementors is a set of boundary conditions that moderate the potential success of the shaping strategy. In the next section, we focus on the mobilization of

[9] That the increase in patenting for both versatility and secondary attributes started prior to 2010 has two explanations. First, while the shift was clear by 2010, some firms started changing their strategy earlier as they became uncompetitive in the main market. Second, when the influx of Chinese silicon PV cell manufacturers took off, the price of silicon surged. This made many believe that the second- and third-generation PV cells would soon present a more favorable cost-efficiency balance compared to silicon-based PV cells, increasing their investments in their secondary attributes and versatile applications.

venture capital investors, the government, and the industry ecosystem for the realization of the new value proposition for the PV cell industry.

4.4. Beyond the Startups: Mobilization of Other Actors in Shaping the Value Proposition

4.4.1. Venture Capital Investors. Pursuing a strategy that appears to be economically irrational challenges how a firm relates to its external environment—particularly to investors seeking economic returns (Pontikes & Barnett, 2017). According to our interviewees, this challenge was evident in the funding for thin-film PV cells after the rise of silicon-based technologies:

> *There is not much enthusiasm amongst venture capital, traditional venture capital, for this sector. I don't think you can find any traditional venture capitalist to put money into these kinds of companies. But there are lots of super angels out there that do put money into this, and the rise of all the billionaires in the millennial and younger age group tend to be very aware of sustainability issues and so they put money into these things that aren't really based on whether a partner cares about the return or not.*

In the wake of the observed shift, venture capital investors retreated from the substantial investments previously made in the sector. As illustrated in Figure 2, although venture capital investment did not cease entirely, it declined markedly, particularly in relation to second- and third-generation technologies. This reduction in investments for startups not conforming to the cognitive logic is in line with prior literature on the negative evaluation of external actors about deviant behavior (e.g., Benner & Ranganathan, 2012; Theeke, Polidoro, & Fredrickson, 2018). The reduced presence of traditional investors created a financing vacuum, compelling startups pursuing shaping strategies to seek alternative funding sources, such as angel investors.

4.4.2. Government. Regarding the role of the government, prior research highlights how government intervention can reshape industry trajectories (Georgallis et al., 2017; Li & Csaszar, 2019). Firms are not only cognizant of the government's potential to provide financial support to accelerate knowledge development (Bruce, de Figueiredo, & Silverman, 2019; Wang, Siegel, & Li, 2024) but also of its capacity to influence the institutional environment (Gao & McDonald, 2022; Uzunca et al., 2018). Consequently, recognizing the strategic importance of institutional support, shaping an industry's value proposition requires an active engagement with policymakers to create a regulatory environment conducive to the diffusion of their technologies and the reconfiguration of market actors' beliefs (Goa & McDonald, 2022; Uzunca, 2018). Reflecting this awareness, several producers of second- and third-generation technologies have publicly advocated for renewed government backing, presenting themselves as the future of the industry. For instance, the founder CEO of Swift Solar, Joel Jean, issued a public letter titled 'Unlocking the future of solar,' in which he makes '*a call for bold US action*' stating: '*The DOE [Department of Energy, sic] has prioritized perovskites for R&D funding, which is a good start. But we need more than just lab breakthroughs. We need a concerted effort to build a robust perovskite manufacturing ecosystem and supply chain clusters. A 'National Perovskite Initiative' would be a game-changer.'* These calls for support also reinforce the plausibility of the "solar everywhere" vision as a credible trajectory for the industry.

Recently, we saw the emergence of supportive legislation, as well as subsidies oriented toward locally developed and manufactured technologies. These changes indicate initial success for firms also trying to shape the normative institutional environment, as some changes are now benefiting them. As one interviewee stated:

> *On the investor side, it's almost like, I would say it's almost a 180 where I think it used to be investors were interested, they would have conversations, they wanted to appear like they're trying to invest or having conversations around solutions like ours that you could say are climate tech or clean tech or green tech related. But there wasn't really a lot of action. There wasn't really a lot of actual investment being put in. And now things are happening with new legislation, new codes, new regulatory things that are put into place, a lot more investment is happening.*

4.4.3. Ecosystem Complementors. The ability to deliver the new proposed value of PV cells—positioned not merely as a commodity but as a differentiated product—is crucially dependent on complementary products and services provided by other firms. Realizing this value proposition requires the formation and coordination of an ecosystem (Kapoor, 2018), which in turn demands deliberate efforts to mobilize external partners and orchestrate their contributions (Ganco, Kapoor & Lee, 2020).

Firms developing second- and third-generation PV technologies face the challenge of building an ecosystem that is distinct from that supporting first-generation technologies, which have already been developed (Guerra & Agarwal, 2024; Szerb & Furr, 2025). These newer technologies rely on different suppliers of manufacturing equipment and categories of installers (Kapoor & Furr, 2015). While first-generation technologies are typically mounted on rooftops or deployed in ground-based solar panels, second- and third-generation technology PV cells are integrated into building materials such as shingles, tiles, and windows, as well as into roadways, vehicles, and fabrics (Guerra et al., 2025; Jacobs & Lee, 2025). This shift necessitates collaboration with new actors, e.g., within the construction industry, from architects to builders, who must be willing to incorporate these novel materials into their routines and workflows.

To promote ecosystem emergence, firms pursuing a shaping strategy must actively engage these complementors by articulating and sharing their vision of the future. However, the lack of a clearly defined technological roadmap and the uncertainty surrounding long-term viability often led to resistance (Dattée et al., 2018). As one interviewee explained, they encountered significant reluctance within the construction industry to adapt existing routines to accommodate PV-integrated windows: '*I think with specifically the building construction market, it's a very conservative market. So, I think historically people have said 'Yeah, we're willing to explore' but at the end of the day they're always like 'We don't want to be first. We want to see this out in the field, we want to see it works, we want to talk to people who have put it up.' And there still is some of that for sure.'* Similarly, challenges for their manufacturing are reported: '*We cannot ask them to pick up a new manufacturing technique or develop a new manufacturing facility.'*

Beyond the challenges of adoption, firms also face gaps in the supporting ecosystem. For instance, an interviewee highlighted the absence of a recycling ecosystem for their specific cell technology, which posed a significant barrier to scaling and long-term planning.

4.5. Drivers of Shaping in the PV Cell Industry

The foundational work on endogenous shaping (e.g., Gavetti et al., 2017; Helfat, 2021; Rindova & Courtney, 2020) suggests that firms engage in shaping activities in pursuit of economic opportunities (Gavetti et al., 2017; Helfat, 2021). Hence, the adoption of shaping strategies by startups in the PV cell industry when facing a threshold that places them at a competitive disadvantage can be understood as a strategic approach to maximize economic rent.

However, the PV cell industry is not solely defined by commercial imperatives; it is also embedded in a quest to address the grand challenge of climate change. Within the industry, there is an understanding that without advancements in the second- and third-generation technologies, it will remain locked in its restricted application in the form of solar panels on roofs or in fields. This would not merely limit the industry from realizing its maximum potential but also curtail its ability to contribute more impactfully toward solving the climate crisis (Hart, 2020).

While economic self-interest undoubtedly plays a role in strategic decision-making, it is important to acknowledge that many startups in the PV cell industry explicitly frame their technological efforts as responses to this larger societal challenge. These startups often communicate a strong sense of purpose, linking their innovations directly to climate action. For instance, Onyx Solar places the United Nations Sustainable Development Goals prominently on its website. Rayleigh Solar Technology declares, ‘*we’re not just passionate, we’re purpose led*,’ and elaborates on its mission with the statement: ‘*imagine solar PV on any surface, anywhere—leveraging the power of the sun for a cleaner energy, a healthier society, and a thriving environment. It’s why we founded Rayleigh*.’ Similarly, Pythagoras Solar describes its vision as follows: ‘*Imagine a world powered by ubiquitous solar where the buildings in which we live and work generate abundant and clean electricity while becoming far more energy efficient. That’s the future Pythagoras Solar envisions*.’ Realforce Solar envisions ‘*making a better world’* while Ubiquitous Energy poses the question, ‘*what if every surface generated renewable energy?’* Swift Solar’s founder CEO, Joel Jean (2025), offers a particularly direct connection between their technology (Perovskite PV cells) and solving the climate crisis: '*It's a real solution that will help us meet our climate goals faster and more affordably. It's also the step change that will help make solar the dominant energy source of the 21st century.*'

For these startups, then, the continued disadvantage of second- and third-generation PV technologies carries implications beyond economic loss. It represents a failure to implement what they view as critical solutions to the climate crisis, raising the possibility that, if current cognitive logics persist, the opportunity to effectively address this grand challenge may be lost.

4.6. Summary of PV Cell Industry Case Study

Our empirical study of the substitution process in the PV cell industry, still ongoing today, compellingly illustrates and grounds our theoretical insights in a real-world context. It demonstrates that prior to the shift in the substitution threshold, startups developing new technologies followed the traditional playbook for technology substitution. They diligently pursued a strategy aimed at improving their cost and efficiency, which are the attributes valued by consumers in the solar panel market. After the substitution threshold shifted dramatically upwards as a result of industrial policies, however, we observe a strategic response from startups developing the new technologies. Now facing an unattainable substitution threshold, these startups responded by trying to shape the value proposition of the industry toward an envisioned future where PV cells are no longer a commodity, but a versatile, differentiated product. This new value proposition benefits their technologies as they outperform the incumbents on the attributes that enable versatility (flexibility, transparency, light weight, and thinness).

5. Discussion

Technology substitution has received extensive attention among strategy scholars. The literature has shed light on the substitution process from both the supply (Dosi, 1982; Tushman & Anderson, 1986) and demand sides (Adner, 2002; Malerba et al., 2007; Tripsas, 2008), while also examining the strategic responses of incumbents when facing an emerging new technology (e.g., Argyres et al., 2015 & 2019; Furr & Snow, 2015 & 2024; Cohen & Tripsas, 2018). This impressive body of research has greatly advanced our understanding of the technology substitution process. However, the research's focus on incumbents' *innovator's dilemma* offered limited guidance for startups developing the new technologies and facing the consequences of the incumbents' actions. For instance, the literature provides limited guidance when the threshold shifts upwards as the incumbent technology improves its performance, making it unattainable. Moreover, by assuming the substitution threshold as an exogenous force, the extant research underestimates the repertoire of strategic responses the actors may formulate.

In this paper, we extend the literature on technology substitution by exploring the shaping of the industry's value proposition as a strategic response when the substitution threshold dynamically shifts upward. Recognizing that the substitution threshold is not exogenous to firms developing new technologies, we theorize that they can employ a strategy aimed at shaping an industry's value proposition that is not confined by the extant substitution threshold. This new value proposition favors the attributes in which the new technology outperforms the incumbent one. By altering the industry's value proposition, the net utility function of the mainstream consumer (substitution threshold) is updated to allow the new technology to be competitive.

Our theorizing on the dynamism in the substitution threshold and shaping as a strategic response to it contributes to the technology substitution literature. First, the extant literature on technology substitution has primarily examined the responses of incumbents to the emergence of a new technology (e.g., Argyres et al., 2015 & 2019; Bigelow, 2018; Eggers & Park, 2018; Furr & Snow, 2015 & 2024). This research, however, has remained mostly silent on the challenges the new technology may face. By examining such a challenge—the upward shift in the substitution threshold—and a potential strategic response to it, we hope that the empirical observations in our case study contribute to a greater understanding of how the firms developing new technologies navigate these challenges. Moreover, these insights bring us closer to a comprehensive understanding of the strategic responses of actors to the changes in the substitution threshold and, in turn, the complexities of the substitution process. Moreover, this study extends research on technology substitution by reconsidering how firms respond to an upward shift of the substitution threshold. Traditional accounts portray the technology substitution process as one in which new technologies must improve along the attributes defining the established, static threshold. However, when the threshold shifts upwards dynamically, such portrayals offer limited guidance and constrain the range of strategic responses available to firms. By linking the technology substitution literature with research on shaping, we conceptualize the substitution threshold as endogenous rather than exogenously given. As such, shaping the industry value proposition emerges as a viable strategic response. Our study broadens the set of strategies through which firms developing new technologies may seek to displace the incumbent technology, offering a more comprehensive account of the technology substitution process.

Second, by highlighting shaping as a strategy in the context of the technology substitution process, we advance the research on endogenous shaping. Only relatively recently have management scholars started developing theories on firms' endogenous shaping (Gavetti et al., 2017; Helfat, 2021; Rindova & Courtney, 2020). This work, however, has yet to elucidate the *when* and *how* of shaping. Little is known about which context or circumstances trigger shaping, or which firm characteristics drive the development and enactment of strategic shaping. Moreover, the process of shaping has been theorized but only occasionally empirically observed (e.g., Jacobs & Lee, 2025; Pathvardan & Ramachandran, 2020; Vinokurova, 2019). Inspired by the institutional entrepreneurship literature, which has a rich tradition of examining firms' proactive strategies that aim to alter their business environment (Pacheco et al., 2010), we document the shaping process by observing communication and resource allocation. As such, we contribute to a more advanced understanding of this process and encourage future empirical studies on endogenous shaping.

5.1. Limitations and Future Research

Our historical case study and the embedded quantitative analysis are not without limitations. First, because the substitution process in the PV cell industry is still ongoing, we could not observe the success or failure of the shaping strategies adopted by startups developing new technologies. While not observing success or failure avoided selection bias in our observations and analysis of shaping as a strategic response, it inhibited us from identifying potential antecedents of success and failure in shaping the value proposition. In another research context, where the substitution process has concluded—either by the substitution of the incumbent or by forestalling the substitution indefinitely—there might be opportunities for future research to examine different strategic responses, their challenges, and their outcomes.

Second, we focused on the strategies that startups developing new technologies pursued to change the industry's value proposition. Several of our data sources suggest that these startups, or at least some of them, together with industry associations, engaged in non-market strategies to also influence the regulations in the institutional environment. As this is beyond the scope of the current study, our empirical context offers an opportunity for future research to explore these non-market strategies and their interaction with shaping.

Third, our study examined the shaping strategies pursued by startups. As we explained earlier, startups face an existential challenge when facing an unattainable substitution threshold. For diversifying firms pursuing new technologies, this is unlikely to be the case. Their strategic responses might be influenced by a set of other issues, such as the redeployability of resources and knowledge developed in other industries. Our focus on startups' strategic responses leaves space for future research to examine diversifying firms' responses.

Fourth, we study the process of a classic technology substitution and not a technology disruption process as defined by Christensen (2015). The new technologies in the PV cell industry demonstrated potential to outperform the incumbent on price and efficiency. At their introduction, however, they were more expensive and underperformed on efficiency relative to the incumbent technology. Despite significant improvements over time with regard to efficiency, bringing the cost down remained their main challenge. As such, the new technologies in the PV cell industry are not disruptive following Christensen's definition. While our theorization does not suggest that startups developing disruptive technologies would respond differently when compared to the startups developing new technologies that do not fit Christensen's definition, it is worthwhile for future research to explore whether this is the case.

Despite these limitations, our study is an important step forward in our understanding of the technology substitution process. It points toward the importance of taking a deeper account of the dynamism in the substitution process and the strategic responses of the actors shaping the dynamic process. Our study illustrates that in the PV cell industry, a sudden, unexpected performance increase by the incumbent technology altered the substitution threshold to a point that it became unattainable for the startups developing new technologies. These startups employed a proactive strategy to reshape the very environment that was constraining their success. We hope that these observations contribute to a deeper understanding of how startups navigate the challenges of the substitution process.

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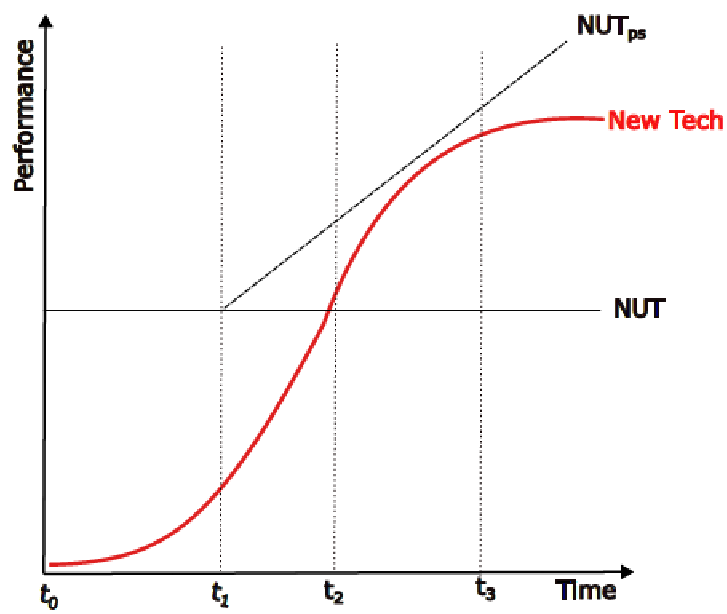
FIGURES & TABLES

Figure 1. The technology substitution process with a dynamic substitution threshold.



NUT = Initial substitution threshold (net utility threshold).
NUT$_{ps}$ = Substitution threshold post shift.
New Tech = Trajectory of new technology

Figure 2. Overview of venture capital investments (VC and CVC) in PV cell startups.

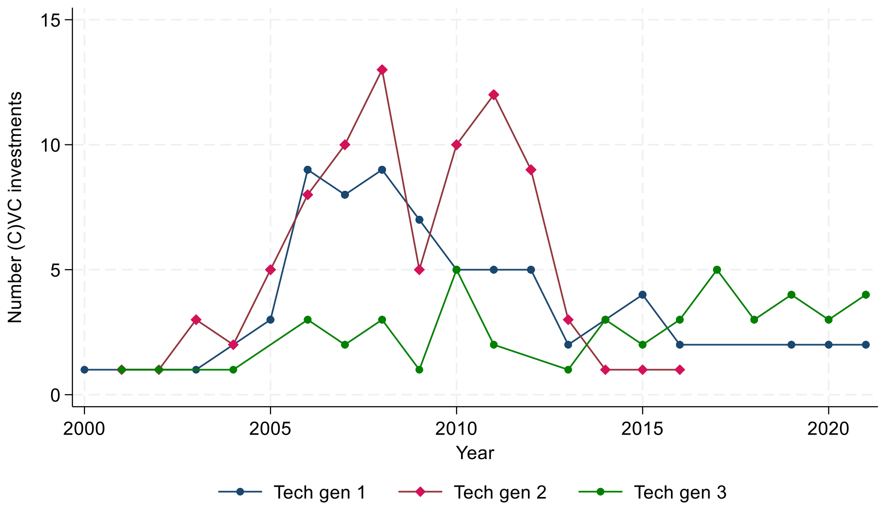


Figure 3. Overview of PV cell firm survival after the upward shift in the substitution threshold.

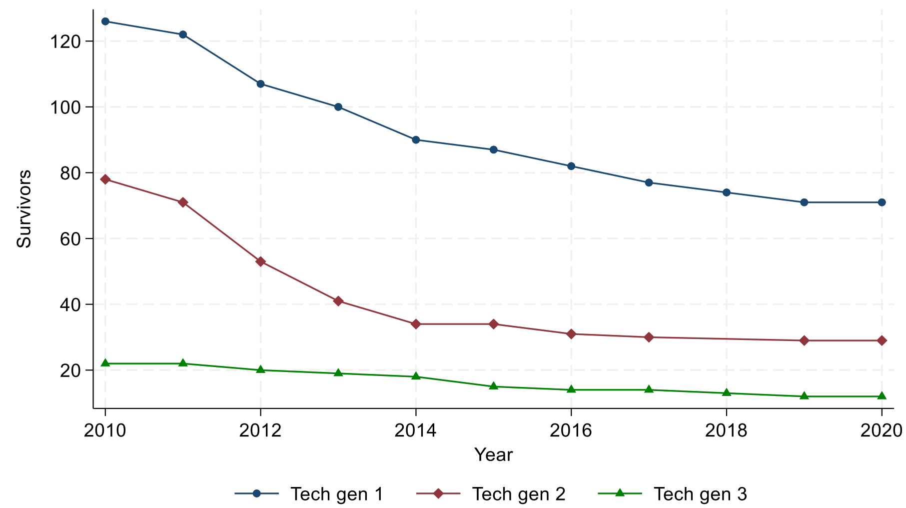


Figure 4. Overview of firms that started commercializing PV cells.

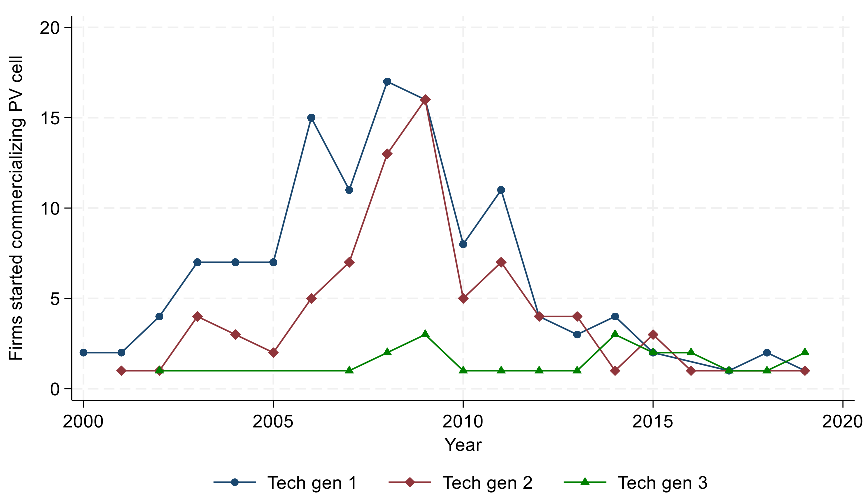


Figure 5. Scores for ‘Versatile applications’ over time (2000-2020).

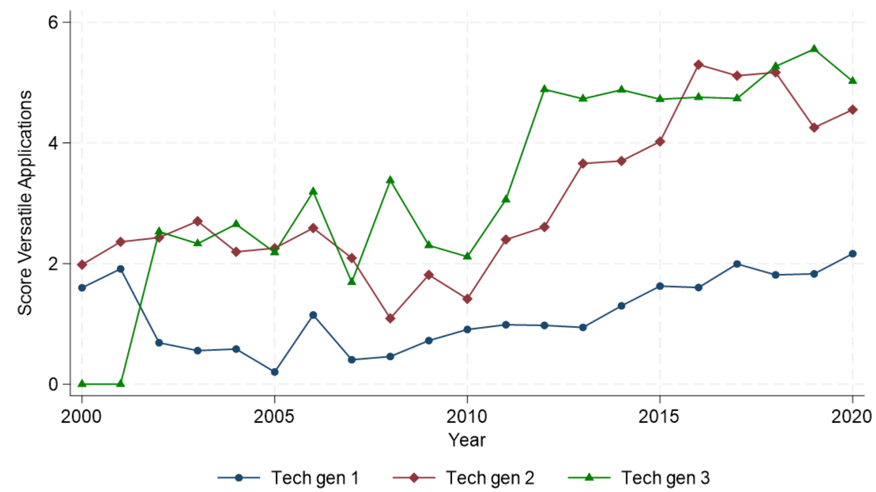


Figure 6. Scores for ‘other attributes’ over time (2000-2020).

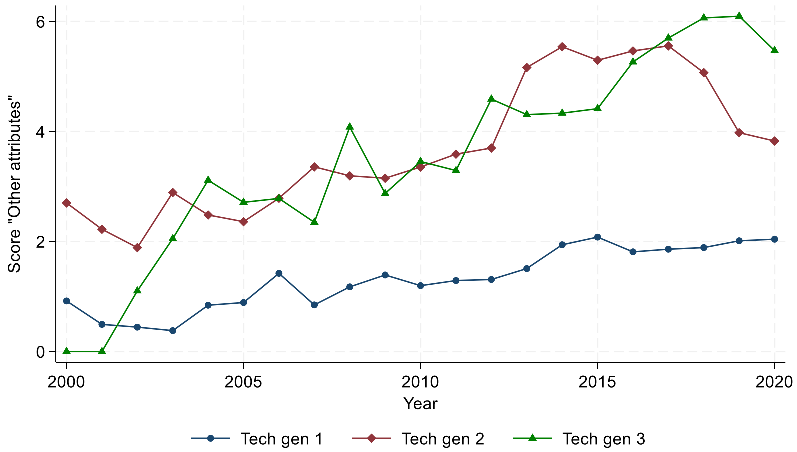


Figure 7. Startups' patenting in PV cells’ versatile applications across PV cell technology generations, pre- and post-upward shift in the substitution threshold.

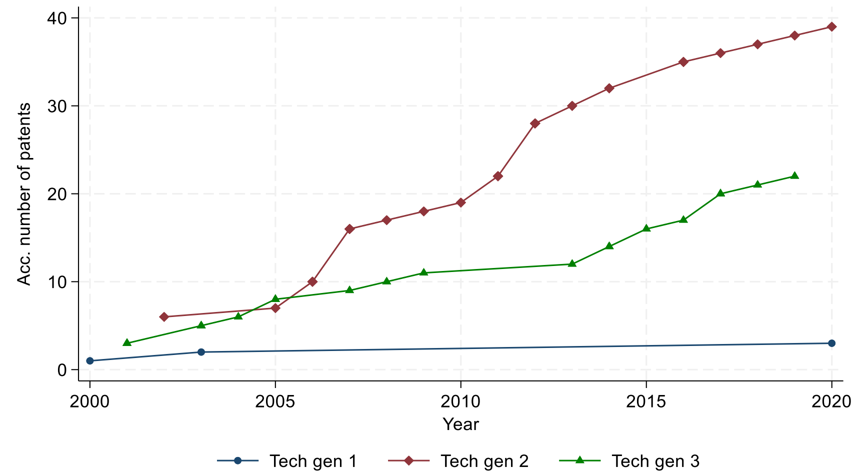


Figure 8. Startups' patenting in PV cells’ other attributes across PV cell technology generations, pre- and post-upward shift in the substitution threshold.

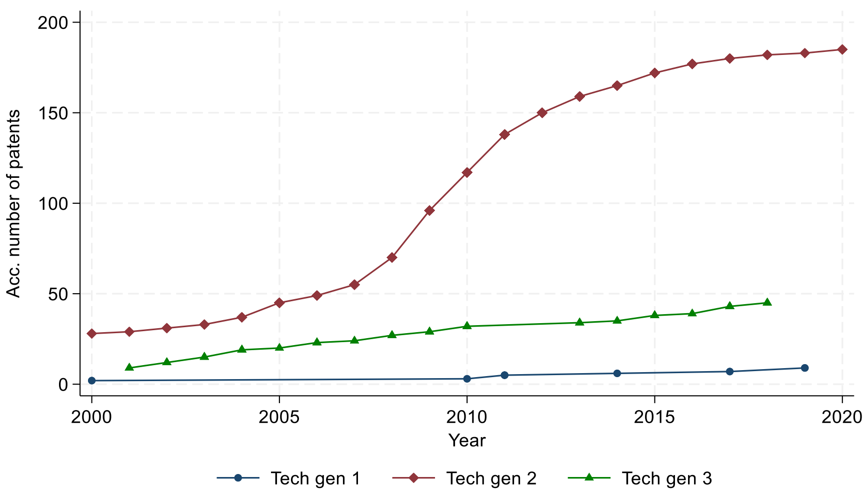


Table 1. T-tests comparing scores for (a) versatile applications and (b) other attributes within and between technology generations. (N = 1328)

(a) Versatile applications

	Pre 2010	Post 2010	*t*	survivor	new firm	*t*
tech gen 1	0.73	1.45	3.93	1.38	1.98	1.77
tech gen 2	1.87	3.73	6.12	3.81	2.97	1.03
tech gen 3	2.40	4.79	4.9	4.68	4.94	0.52
1 vs 2	5.19	10.09				
1 vs 3	5.98	14.08				
2 vs 3	1.37	3.14				

(b) Other attributes

	Pre 2010	Post 2010	*t*	survivor	new firm	*t*
tech gen 1	1.08	1.73	3.41	1.77	1.46	0.87
tech gen 2	2.98	4.56	5.12	4.63	3.86	1.03
tech gen 3	2.88	4.98	4.49	4.85	5.16	0.67
1 vs 2	7.4	12.8				
1 vs 3	5.74	14.12				
2 vs 3	0.21	1.35				