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From technology race to technology marathon: A behavioral explanation of technology advancement

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ABSTRACT

In industries characterized by continual progress from lower to higher generations of technology, firms seek to solidify their competitive position by deploying technologies more advanced than their current ones. This study attempts to provide behavioral explanations for the degree of technology advancement pursued by a firm. Using data from the flat panel display industry, we find that the extent of a firm's technology advancement is largely determined by how far it falls below the industry average. Our findings complement prior research on technology races by suggesting that firms in the thin-film-transistor liquid-crystal display (TFT-LCD) industry largely attempt to run a “marathon” rather than a sprint: the degree of technology advancement is mainly guided by a desire not to fall behind the pack as opposed to trying to move ahead of the pack in order to win the race. By the same token, firms exceeding the industry average in their technology reveal little motivation even to maintain their lead, much less extend it.

1. Introduction

Rapid technological progress in high-tech industries often triggers a technology race that pushes the technology frontier outward (Khanna, 1995). In many technology markets the locus of competition revolves around a sequence of co-existing generations of technologies emerging along a clearly defined technological trajectory. Firms in such product markets often confront a critical decision on *technology advancement* [2]: by how much should they advance the level of the technology in their products (Gaba & Bhattacharya, 2012)? This decision is fraught with major strategic implications stemming from a basic tradeoff. On the one hand, advancing the firm's current technology strengthens its competitive position (Mas-Ruiz & Ruiz-Moreno, 2011); on the other hand, moving too far ahead may expose the firm to costs and risks inherent in uncharted territory (Chen & Miller, 2007).[3] Firms undertake varying degrees of technology advancement when faced with this tradeoff: some firms may move in small steps by deploying technologies that are only slightly more advanced than their current ones, while others may be more aggressive by leaping over several generations at once. One question naturally arises: Which factors can help explain variation in the degree of technology advancement among firms?

Despite many studies of how firms advance their technology (e.g., Aghion, Harris, & Vickers, 1997; Bohlin, Gruber, &

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[2] Technology advancement here refers to a firm's adoption of a technology generation more advanced than its currently deployed technology generation, where the sequence of technology generations is determined by the technological trajectory of the industry. Technology advancement is a sub-group of technological change, which broadly includes two types of technological regime – Schumpeter Mark I and II. Unlike Schumpeter Mark I characterized by “creative destruction,” Schumpeter Mark II is characterized by “creative accumulation” where established firms deepen their technological learning and accumulate technological capabilities over time (Malerba & Orsenigo, 1996). This study focuses on the technological change of Schumpeter Mark II in which established firms identify the industry's technological trajectory on which incremental process improvements are made (Tushman & Anderson, 1986).

[3] The TFT-LCD industry provides a case in point. The huge capital investment involved in advancing to higher generations as well as large fluctuations in industry demand put firms deeply into the red (Hu, 2012; Lee et al., 2011; Wu et al., 2012). Leading panel manufacturers— Sharp, Samsung and AU Optronics — invest heavily in R&D and facilities. In 2012, Sharp reported the largest loss of 4.67 billion USD in its history. Samsung spun off its LCD division after a single year loss of 9.67 billion USD in 2011. AU Optronics posted losses four years in a row even as it recorded its largest-ever sales during the same period.

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Koutroumpis, 2010; Leiblein & Ziedonis, 2007), only a couple studies (Lee, Kim, & Lim, 2011; Lerner, 1997) have examined specifically the *degree* of technology advancement undertaken by firms. Prior studies have generally analyzed technology advancement decisions by firms as competitive moves in a technology race, focusing mainly on the strategic dynamics underpinning such technology moves. Advancement moves are seen as the revealed strategy of firms (Aghion et al., 1997; Bohlin et al., 2010). These important studies leave somewhat open, however, just what is driving the decision-making process of individual firms in determining their degree of technology advancement. In order to gain deeper insight into firm decision-making processes we focus specifically on *behavioral* factors underlying the firm's technology advancement decisions. We endeavor to isolate behavioral factors from other influences so as to derive a more theory-based understanding.

To this end, this paper builds upon the perspectives of problemistic search and slack search from the behavioral theory of the firm (BTOF) to study technology advancement. These perspectives can explain a variety of risk-taking behaviors by firms (Massini, Lewin, & Greve, 2005; Miller & Chen, 2004). The empirical relevance of these two theoretical perspectives has been demonstrated for many strategic decision areas, including corporate venture capital (Gaba & Bhattacharya, 2012), R&D intensity (Chen & Miller, 2007; Greve, 2003), and innovation (Nohria & Gulati, 1997).

Bridging the BTOF and the technology management literature, we hypothesize that when a firm's technological performance exceeds its aspiration level, the degree of technology advancement undertaken by the firm decreases as the performance-aspiration differential increases; when a firm's technological performance falls below its aspired level, the degree of technology advancement increases according to the size of its performance-aspiration gap. Using data from the global thin-film-transistor liquid-crystal display (TFT-LCD) industry from 1990 to 2009, we find evidence supporting these hypotheses.

Our study makes both a conceptual and technical contribution to the technology management literature. At a conceptual level, our study is the first to recast the concept of the "technology race" (Khanna, 1995; Lee et al., 2011; Lerner, 1997) as a "technology marathon" in which firms are evidently motivated less to finish first than simply to stay in the race. The behavioral component of their technology advancement, complementing the oft-cited perspectives of firm capabilities and competitive dynamics (Eggers, 2014; Lee et al., 2011), helps explain why firms in at least some technology arenas (like the TFT-LCD industry) may aspire to gravitate toward the center of the pack where they are protected by headwinds rather than expose themselves to such headwinds by leading or trailing the pack. Some empirical work connecting technology competition and aspiration has just begun to emerge (e.g., Giachetti & Lampel, 2010). Our study builds on this connection by delving deeper into the behavioral factors that motivate or demotivate a firm's technology advancement (Nohria & Gulati, 1997). At a more technical level, with the exception of Lerner (1997) and Lee et al. (2011), prior research in technology management has treated technology advancement decisions as a simple binary variable (advance vs. not-advance) (e.g., Bohlin et al., 2010; Leiblein & Ziedonis, 2007). In contrast, our study treats technology advancement as a continuum (i.e., degree of technology advancement undertaken) and is the first to apply the behavioral theory of the firm specifically to predict the degree of technology advancement.

The remainder of the paper is organized into three sections. The first of these sections presents a brief literature review and theory development. The second section describes the empirical context, methods and results. The third section expands on the implications of this study for the distinction between technology "races" with finish lines and technology "marathons" without finish lines. Suggestions for future work are followed by a concluding note.

2. Theory development

2.1. Technology advancement in review

The study of technology advancement pertains to firm decisions in industry segments featuring patterns of sequential technological progression (Norton & Bass, 1987). Such technological progression in many high-technology industries — e.g., the DRAM industry (Kapoor & Adner, 2012), the semiconductor industry (Leiblein & Madsen, 2009), and PC microprocessors (Ofek & Sarvary, 2003) — has given rise to the notion of the "technology generation," which is essentially "a particular form or variation of technological solution, but shares the underlying scientific principles of all other generations" (Taylor & Taylor, 2012, p. 548). In such industries, firms will generally advance sequentially from one generation of technology to the next.

The economic costs associated with technology advancement have typically been considered the principal factor tipping the scales one way or other in a given firm's decision-making process. Such costs include those of developing and introducing the next generation of technology (Nault & Vandenbosch, 1996), the compounded cost for laggards of moving up the learning curve due to time compression diseconomies (Leonard-Barton, 1992), and the opportunity cost of waiting. The more advanced the technology, the more costly technology advancement is (Horner, 2004). A variety of factors affect these costs. For example, Leiblein and Ziedonis (2007) examine the effect of technological uncertainty on the decision to advance to future generations of technology. Other scholars investigate the impact of entry timing, for example by arguing that second mover advantage may eventually prevail as the follower will face less technological uncertainty and hence lower costs than the leader (Forbes & Wield, 2000).

The technology race literature expands on these phenomena by factoring in the competitive and fluid nature of the relationship between technological leader and follower (Khanna, 1995; Lee et al., 2011), or more specifically, the position of a firm's technology relative to the technology frontier. This body of work assumes either the view of the leader or that of the follower in examining technology advancement decisions. The technology leader advances to push the technology frontier outward so that it can increase its lead over followers (Nault & Vandenbosch, 1996), so-called "protection through preemption" (D'Aveni, 1994). Once the lead becomes significant enough, the leader can start hitting the brakes intermittently (Ofek & Sarvary, 2003). Scholars typically assume that technology development progresses in a linear order like trains making stops along a fixed route (Bohlin et al., 2010). Technological followers predominantly choose catch-up strategies, moving up the trajectory to pull even with leaders at the frontier (Lee et al., 2011) and occasionally leapfrogging them (Leiblein & Ziedonis, 2007). Besides moving to or beyond the frontier, followers may stand in the shadow of leaders to purposely trail behind the frontier (Wang, Yang, Miller, 2015). All of the just-mentioned technology strategies regard the frontier as the focal point of competition and focus on the gap between technological leaders and close followers. The view from these strategies thus relegates to secondary importance the technology advancement made by firms positioned at a significant distance from the technology frontier. The following analysis, in contrast, strives to encompass the full range of firms on a given technological trajectory.

With only a couple exceptions (Lee et al., 2011; Lerner, 1997), prior work treats the firm's technology advancement decision as a binary variable, i.e., to advance or not (Bohlin et al., 2010; Leiblein &

Ziedonis, 2007). Analyzing technology advancement as a continuous rather than dichotomous variable promises to provide a more refined understanding of firms' technology advancement strategies. Often the pertinent decision is not whether or not to advance a given technology, but rather by how much. This is especially the case when several different technology generations are available as options; in many industry settings, selecting among multiple technology generations featuring different technical specifications is more relevant than the simple decision of “advance versus not advance.”

Beyond just the simplified operationalization of the dependent variable, virtually all prior empirical work on technology advancement has been theoretically eclectic: economic, technological, behavioral, and competitive perspectives have been mixed together in explaining patterns of firm decision making. The next logical step is to disentangle the relevance of these theoretical strands. As a first effort in this direction, we focus specifically on behavioral factors in technology advancement decisions. We do this for two reasons. First, technology advancement represents a risk-laden activity, since a greater degree of advancement entails higher technical and financial uncertainty (Hu, 2012; Lee et al., 2011). As such, technology advancement relates to the risk-preference adjustment emphasized in the BTOF, where aspiration-driven organizations engage in R&D and develop new technologies to improve performance (Gavetti, Greve, Levinthal, & Ocasio, 2012; Greve, 2003). Second, technology advancement represents a form of “organizational search” (Cyert & March, 1963) for new solutions to problems. Technology-intensive firms are more likely to engage in local search for nearby solutions (Ahuja & Lampert, 2001), whereas firms trailing in their technological performance will scale up their R&D efforts in search of more distant solutions (Chen, 2008). Using data from the U.K. mobile phone industry, Giachetti and Lampel (2010) show that the radicalness of adopted technology is determined by a firm's distance from its targeted rivals. These studies posit technology advancement as a form of search behavior. We therefore draw upon the BTOF perspectives of slack search and problemistic search as the theoretical basis of this study.

2.2. Firm behavior in relation to aspiration: perspectives of slack and problemistic search

The BTOF beginning with Cyert and March (1963) has been extraordinarily influential by virtue of its seminal concepts, assumptions, and predictions concerning a variety of research topics, such as cognition, performance feedback, learning and adaptation (Gavetti et al., 2012; Starbuck, 2013). Key concepts covered by the BTOF include bounded rationality, problemistic search, dominant coalitions, standard operating procedures, and slack search (Argote & Greve, 2007). When a firm's performance deviates from its aspiration, either “attainment discrepancy” (Iyer & Miller, 2008) or “organizational slack” (Cyert & March 1963; Tan, 2003) will result, altering its risk preferences as well as its search behaviors (Greve, 2003).

Theories of slack search and problemistic search are two particularly useful perspectives for studying the decision-making processes behind organizational search efforts. These two perspectives lead to very different predictions concerning which firms will engage in distant organizational search, however. The slack search perspective predicts higher levels of innovation in a firm performing *above* its aspiration level. A surfeit of resources can motivate such a firm to enlist slack resources in search activities such as R&D initiatives (Greve, 2003) and new product launches (Argote & Greve, 2007). In contrast, the problemistic search theory predicts higher levels of innovation in a firm performing *below* its aspiration level (Argote & Greve, 2007). Both perspectives require discussion as to the formal and operational definition of aspiration level. As a preliminary step, we first distinguish social aspiration from historical aspiration.

2.3. Technological aspiration levels: social aspiration vs. historical aspiration

According to the BTOF, firms adjust their risk preferences and set their distance of organizational search after assessing their performance relative to their aspiration level (Chen, 2008; Cyert & March, 1963; Greve, 2003; Iyer & Miller, 2008). As a yardstick for defining firm performance as low or high, aspiration level is often captured by the firm's past performance (historical aspiration) or by its performance relative to the industry as a whole, in which case one speaks of social aspiration (see Bromiley & Harris, 2014 for a review).

The concept of social aspiration can be assumed to be more relevant to technology races than historical aspiration, given that a firm's social aspiration is defined relative to competitors and hence incorporates a competitive dimension. When the technology frontier is pushed outward by the technology advancement of leading competitors, the firm's existing technology is rendered increasingly obsolete. Its relative technological performance decreases, possibly with declining financial performance as well. By the same token, if no firm advances its technology, other firms can passively maintain their level of technological performance. It is customary in BTOF studies to set the benchmark aspiration level to the average performance of the industry or to that of a subgroup of selected firms with similar characteristics (Massini et al., 2005).[4] In such competitive settings, historical performance comparisons may provide a less relevant benchmark for decision making (Arrfelt et al., 2013).

Adopting social aspiration as the relevant benchmark, we postulate that firms assess their technological performance against an aspiration level equal to the average technological performance of the industry as a whole. When a firm advances beyond the industry average, it is assumed to have taken its technological performance above its aspiration level. Alternately, if a firm's currently deployed technology lags behind the industry average, its technological performance is considered to be below its aspiration level. Many prior studies have used the industry average to gauge the aspiration level for financial performance (Bromiley & Harris, 2014; Chen, 2008; Fiegenbaum, 1990) and innovation performance (Gaba & Bhattacharya, 2012; Madsen & Leiblein, 2015). In line with characteristic BTOF thinking, we extend the use of industry averages to aspiration levels in technological performance.

Below we distinguish between the scenarios of a positive aspiration-performance gap (i.e., above-aspiration performance) and a negative gap (i.e., below-aspiration performance) to predict their disparate effects on a firm's technology advancement. Although we ultimately predict BTOF theories to be more relevant in the case of negative gaps, the BTOF perspective nonetheless remains vital to the empirical study as a whole by leading us to assume positive and negative gaps to be fundamentally asymmetric in their effects and hence to separate positive from negative aspiration-performance gaps in the statistical analysis.

[4] Conversely, if a firm's technological performance is clearly less a function of what its peers do, as for example in the case of firms engaged in pioneering technology, the notion of historical aspiration based on comparison of a firm's current and past performance may well be more relevant.

2.4. When technology performance is above the firm's social aspiration level

In general, a firm's risk-taking propensity may change if above-aspiration performance results in a surplus of resources (Fiegenbaum, 1990), possibly leading to so-called slack search (Wiseman & Bromiley, 1996). Contrasting arguments have been developed as to the applicability of slack search (Greve, 2003). Some studies argue that when a firm has achieved above-aspiration performance, it might choose to engage in distant search or take exceptional risks because of surplus resources (Argote & Greve, 2007). In contrast, other studies argue that higher performance will instead result in risk avoidance (Ahuja & Lampert, 2001), because a firm exceeding its aspiration level is simply not motivated to take on more risk (Chen, 2008) and may even curtail risk-laden activities such as R&D (Greve, 2003).

For a couple of reasons, we anticipate that above-aspiration technological performance in arenas like the TFT-LCD industry will not result in slack search. First, slack search is often conducted to identify opportunities that can add to or complement a firm's existing operations. Such opportunities are less attractive in the case of technology advancement along a clearly defined technological trajectory (Dosi, 1982), as newer technologies can encroach upon current sales or entail potentially greater risk by inviting new competition. For example, AU Optronics had two options for technology advancement in 2004 — advancing one or two generations (Wu, Li, Ong, & Pan, 2012). AU Optronics could continue producing panels for personal computers if it advanced one generation. Jumping two generations ahead would allow AU Optronics to ramp up its production of higher-margin large-size TVs. However, competition was keen and demand was difficult to predict. In the end, AU Optronics chose to advance only one generation.

Second, though above-aspiration technological performance can sometimes result in slack *technological* resources, these resources do not necessarily translate into slack *financial* resources (Wiseman & Bromiley, 1996). Yet it is financial resources that are necessary to fund higher-risk efforts at technology advancement.[5] Indeed, Lerner (1997) advises studies of technology advancement to steer clear of predictions based on financial performance since high-technology industries are cyclical and constantly alternating between booms and busts (Lee et al., 2011). A firm will most likely hoard slack financial resources to cope with uncertain future contingencies. Even if financial slack materializes, any positive effect on technology advancement efforts may be negligible.

In sum, we posit that when a firm's technological performance exceeds its aspiration level, incentives to engage in slack search will be overridden by competitive and financial risks in the industry, and hence such firms will be less likely to make big technological bets. In formal terms:

Hypothesis 1. *The more a firm's technological performance exceeds its technological aspiration level, the smaller the step it is likely to take in pursing technology advancement.*

Despite negative predictions about the effect of slack search, the BTOF remains operative in two ways in the following analysis: first, by defining the firm's perceived performance in relation to the firm's social aspiration levels, and second, by obliging the empirical analysis to separate above-aspiration performance impacts from below-aspiration performance impacts on technology advancement decisions.

2.5. When technology performance is below the firm's social aspiration level

In the case of below-aspiration performance, the firm engages in problemistic search (Argote & Greve, 2007). The theory of problemistic search posits that the gap between a firm's aspiration level and its actual performance affects the firm's framing of problems as well as its willingness to engage in search and other risk-taking behaviors (Miller & Chen, 2004). A firm performing below its aspiration level may be more motivated to explore new investment opportunities (Iyer & Miller, 2008) or product launch initiatives (Gavetti et al., 2012), and generally more willing to assume risk than it otherwise would be. For instance, Chen (2008) found higher R&D expenditures among firms with declining financial performance. Similar considerations apply to the decision making of firms involved in technological competition. Since technology continually advances forward, below-aspiration performance intensifies the firm's perceived risk of technological obsolescence.

Below-aspiration performance signals a gap between a firm's technological capabilities and those of more advanced firms (Capron & Mitchell, 2009). A forward-looking firm is likely to engage in problemistic search (Chen, 2008), lest advancement of other firms in the technology race renders its technological capabilities even more inadequate (Chen & Miller, 2007; Greve, 2010). The development of new capabilities takes time, and the further a firm's capabilities lag, the higher the development costs. Accordingly, a firm cannot afford to fall too far behind and risk entering into the proverbial "death spiral" (Leonard-Barton, 1992). Instead, a firm will be better served by deploying a more advanced technology before the performance-aspiration gap shows signs of widening.

Hypothesis 2. *The more a firm's technological performance is below its technological aspiration level, the larger the step it is likely to take in pursing technology advancement.*

3. Methods

3.1. Industry context

The TFT-LCD industry is a setting of tremendous technology advancement since commercial production began in 1989 (Murtha, Lenway, & Hart, 2001). TFT-LCD has been the key technology to manufacturing display panels as it is more attractive than other competing technologies for ease of commercialization and superior technological performance. Throughout the observation period TFT-LCD accounted for more than 90 percent of the annual production value of flat-panel displays. Introductions of new generations have been frequent (Lee et al., 2011). In just 20 years, the TFT-LCD industry has evolved from the 1st generation (Gen 1, size 300 mm × 350 mm) in 1989 to the 10th generation (Gen 10, size 2880 × 3080 mm) in 2009, offering a wide variety of sizes and generations for TFT-LCD panel makers to produce. The manufacturing of displays is performed on a large sheet of glass substrate, which is later subdivided into separate display panels. Manufacturers of glass substrates (e.g., Corning) essentially set the pace and parameters of the technology race by developing and offering new glass substrate sizes that TFT-LCD panel makers can decide to adopt or not adopt. In other words, glass substrate size is the primary bottleneck TFT-LCD panel manufacturers have to contend with. As in the semiconductor industry, the TFT-LCD industry uses the concept of generations in technological

[5] Even financial slack is a complicated concept. Wiseman and Bromiley (1996: 531) distinguished three types of financial slack: (1) available slack represented by the current ratio; (2) recoverable slack represented by selling, general and administrative expenses divided by sales; and (3) potential slack represented by the debt to equity ratio and the interest coverage ratio.

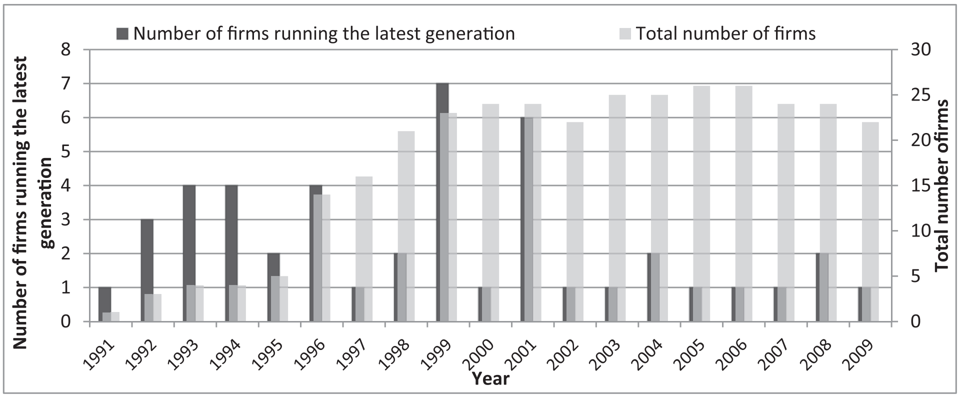

Fig. 1. Evolution of generations over time.

specifications.

The technology generation is a simple, visible and industry-wide accepted measure of firms' technological sophistication (Murtha et al., 2001). Information on firms' current and upcoming technology generations is readily available on their corporate website, among other public sources. Firms can easily ascertain their competitors' next generations through press releases or by tapping their suppliers.[6] Panel manufacturers routinely announce their plant construction plans and specify the amount of capital involved. As shown in Fig. 1, there were more firms at the forefront, i.e., running the latest generation, before 2000 (left axis); meanwhile, the total number of firms in the industry has increased over the years, peaking in the late 2000s (right axis). While older generations of TFT-LCD technology can and do coexist with newer generations, firms are generally motivated to offer more advanced technology products to obtain higher profit margins.

This industry enables us to observe historical patterns of each firm's technology advancement decisions over time (Eggers, 2014). Fig. 2 reveals the heterogeneity of technology advancement behavior among some representative players. Toshiba Matsushita was the front-runner when the industry experienced its first wave of mass production, but it has given up deploying the latest generations since then. Sharp and Samsung have each taken turns deploying the latest generations since the late 1990s and both have leapfrogged over more than one generation at a time. LG Display and AU Optronics entered the industry later and have often deployed technologies that are a generation ahead of the average. BOE Hydis has been relatively inert, with only one advancement over the years.

3.2. Data sources

We collected data primarily from the annual publication by Fuji Chimera (Japan), *Flat Panel Display Applications: Trend and Forecast*, which covers the years from 1998 through 2010. These annual reports provide production and market-related data for all firms in the global TFT-LCD industry. The second data source is *Dynamics of the Flat Panel Display Industry*, published annually by the Photonics Industry and Technology Development Association (Taiwan) from 1991 through 2010. This report is similar to that of Fuji Chimera, except that it focuses primarily on Taiwanese and Chinese firms. The combined data sources provided over 1000 firm-year observations. Financial data were collected from annual reports. Supplemental data sources include the Nikkei Microdevices' *Flat Panel Display Yearbook*, which provides data prior to 1998. Due to incomplete data on variables like market share and licensing, we ended up with an unbalanced data set containing 350 firm-year observations over the years 1990–2009.

3.3. Variable measures

3.3.1. Dependent variable

Degree of technology advancement. When a firm opens a plant with a generation of technology higher than its current one, the firm's decision to engage in technology advancement has been implemented. A firm that advances its technology will encounter risks originating from substantial and irreversible capital investment (Wu et al., 2012). The more advanced the technology, the more costly the advancement will be. For example, the cost of building a new Gen 5 plant is 1 billion USD. Building a Gen 7 plant costs 2 billion USD, and Gen 10 almost twice as much at 3.5 billion USD (Hu, 2012). The risks of technology advancement are not only financial in nature. The larger the glass substrate involved in producing displays, the higher the costs, technological hurdles, and level of complexity. Among other things, the difficulty of pouring liquid crystal between sheets of glass increases with size. Larger glass is heavier and more likely to bend during transit between work stations; it is also more likely to catch dirt and particles, rendering finished products defective. Finally, larger glass plates are more likely to have an uneven surface, raising the difficulty of printing electric circuits. Failure to troubleshoot technological problems can result in financial stress if production yields are not stable enough to secure orders.

We use two complementary indicators, growth in substrate size (Lee et al., 2011) and increase in generations (Murtha et al., 2001), to measure technology advancement in the TFT-LCD industry. Concerning the first measure, as in Lee et al. (2011), we measure the degree of firm *i*'s technology advancement according to the size growth of its largest glass substrate from year t to year t+1.

$$\textit{Size growth}_{it} = \frac{s_{i(t+1)}}{s_{it}} - 1$$

Concerning the second measure, the progression of TFT-LCD technology can also be charted by its generation number corresponding to a specific size of glass substrate. Our second measure of technology advancement is the number of generations advanced by the firm in a given year, measured as Gen_{t+1}-Gen_t. The relationship between substrate size and generation of TFT-LCD technology is shown in Table 1. The growth in substrate size is not constant across

[6] Based on our interviews with industry participants in 2012.

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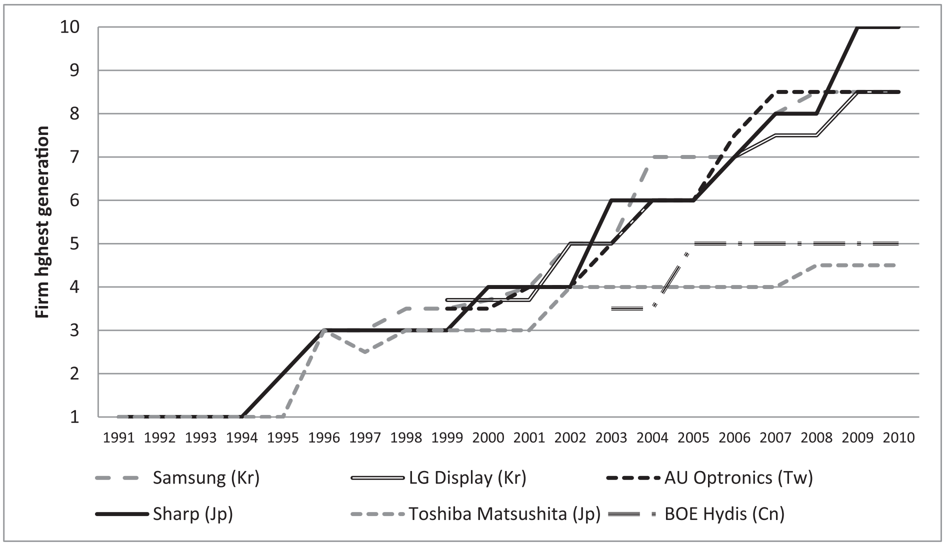

Fig. 2. Technology advancements by selected firms.

generations. For instance, from Gen 1 to Gen 2 the size growth is 59%, whereas from Gen 6 to Gen 7 the size growth is only 48%. We ran separate regressions on these two measures of technology advancement.

3.3.2. Independent variables

Technological aspiration and performance. In the TFT-LCD industry, firms often run multiple plants with different generations of technology in a given year. For our calculations, we select the highest of a firm's total generations in use. Consistent with the focus of BTOF research on the behavior of firms at an aggregate level rather than firm-specific strategies, we model the technological aspiration level as equal to the industry average of technology deployed; here we adopted the measures used by Madsen and Leiblein (2015) whose study of the semiconductor industry noted technical processes and patterns of innovation similar to those of the TFT-LCD industry. The more a firm's highest generation exceeds the industry average in a given year, the more this firm transcends its aspiration level (Giachetti & Lampel, 2010). Conversely, a firm falls below its technological aspiration level when its highest generation is lower than the industry average.

We first obtain the average of all firms' highest technology generation in the industry in a given year, $\overline{Gen}_t$. Then we calculate the difference between an individual firm's highest generation and the industry average. From that we segregated the firm's technological performance into above- or below-aspiration differences using a spline function (Greve, 2010):

$$\text{Technological aspiration } \overline{Gen}_t = \frac{\sum_i^N Gen_{it}}{N_t}$$

Table 1
Correspondence between generation and size of glass substrate.

Generation	Glass substrate size	Year	Size growth (%)
0	270 × 200 mm	1987	–
1	300 × 350 mm	1990 Q3	94
2	360 × 465 mm	1994 Q2	59
2.5	400 × 500 mm	1995 Q3	19
3	550 × 650 mm	1995 Q3	79
3.5	650 × 830 mm	1997 Q3	51
4	680 × 880 mm	1997	11
4.5	730 × 920 mm	2003	12
5	1100 × 1300 mm	2002 Q2	11
5.5	1320 × 1500 mm	2004 Q3	38
6	1500 × 1850 mm	2003 Q2	40
7	1870 × 2200 mm	2004 Q3	48
7.5	1950 × 2250 mm	2006 Q1	7
8	2160 × 2400 mm	2007	18
8.5	2200 × 2500 mm	2007 Q3	6
10	2880 × 3080 mm	2009 Q4	61

Source: Authors' data and Lee et al. (2011).

$$\text{Below} - \text{aspiration performance} = \begin{cases} -\left(Gen_{it} - \overline{Gen}_t\right), & Gen_{it} - \overline{Gen}_t < 0 \\ 0, & Gen_{it} - \overline{Gen}_t \geq 0 \end{cases}$$

We used absolute values of both above- and below-aspiration measures. Example: The industry is composed of firm A and B. Firm A's highest generation is Gen 6, and Firm B's is Gen 3. The industry's average generation is 4.5 in a given year. Firm A's above-aspiration performance will be 1.5 (=6−4.5) and its below-aspiration performance will be zero. Firm B's above-aspiration performance will be zero, and its below-aspiration performance will be 1.5 (=-(3−4.5)).

$$\text{Above} - \text{aspiration performance} = \begin{cases} Gen_{it} - \overline{Gen}_t, & Gen_{it} - \overline{Gen}_t \geq 0 \\ 0, & Gen_{it} - \overline{Gen}_t < 0 \end{cases}$$

3.3.3. Control variables

We included several variables to control for other influences. First, a firm's decision to deploy a more advanced technology may be affected by economic results stemming from its current technology. To address this, we have included four measures: 1) *market share*, the ratio of a firm's production value to the industry's total production value in a given year. Greater market power typically encourages a firm to take on more risk due to higher expected returns on innovation (Mas-Ruiz & Ruiz-Moreno, 2011); 2) *change in financial trend*, the positive or negative differential between financial performance in a given year and that in the prior year. We used a spline function to operationalize this measure:

$$\textit{Positive financial trend} = \begin{cases} ROA_{it} - ROA_{it-1}, & ROA_{it} - ROA_{it-1} \geq 0 \\ 0, & ROA_{it} - ROA_{it-1} < 0 \end{cases}$$

$$\textit{Negative financial trend} = \begin{cases} -(ROA_{it} - ROA_{it-1}), & ROA_{it} - ROA_{it-1} < 0 \\ 0, & ROA_{it} - ROA_{it-1} \geq 0 \end{cases}$$

We also included 3) *diversification* to distinguish between the impact of financial results on firms uniquely dedicated to flat panels as opposed to units in larger conglomerates: 1 indicates that the manufacturer is a business unit in a conglomerate and 0 otherwise. 4) Ferrier, Fhionnlaoich, Smith, and Grimm (2002) imply that financial distress is a catalyst of aggressive competitive behavior. We used the logged *total debt* to measure a firm's total liability (in millions of USD) as a proxy for potential financial stress motivating technology advancement. We converted total debt reported in non-USD currencies on the basis of the currency conversion rate on December 31st of each year.

Second, a firm's technology advancement decision can depend on its available resources and experience. To address this, we have included the following control variables. 1) *Investment*, an indicator of a firm's available financial resources for meeting future demand, measured as the logged annual outlay on equipment (in millions of USD). 2) Considering that large firms tend to be more capable of raising funds than smaller firms, and lenders may experience more acute information asymmetry problems with smaller firms than with larger firms, we control for the effect of firm size by including the log of the firm's *total assets* (in millions of USD). 3) *Firm age* is used to capture a firm's experience with innovation and managing competition, measured as the number of years a firm has been in operation since opening its first flat panel plant. Finally, technology firms engage not only in competition, but also in collaboration (Gnyawali & Park, 2011). For instance, the licensing relationship a firm has with its competitors affects the firm's decision to advance its technology (Wang et al., 2015). To control for effects of co-opetition, we included three measures that capture different types of technology licensing. 4) *Licensing with leader* counts the number of technology transfers that a firm received from and issued to firms running the industry's highest generation in a given year. We repeat the same operationalization for the variables 5) *licensing with outsider* and 6) *licensing with laggard*. An outsider refers to a firm not directly receiving sales from flat panel manufacturing, such as a patent house. A laggard is a firm operating generations lower than the highest generation in a given year.

Third, we controlled for competitive pressures arising from the industry and institutional context: first, we added *year dummies* to capture the effects of the movement of the frontier and other industry-related effects not captured elsewhere; second, we added *nationality* dummies to control for the effect of government policies on capital markets and technology transfers (Spencer, Murtha, & Lenway, 2005), basing the variable on the location of a firm's headquarters (Japan, Korea, Taiwan, and rest of the world).

Test statistics raised concerns about autocorrelation and heteroskedasticity.[7] We fitted panel-data linear models using feasible generalized least squares (FGLS), which allows for estimation in the presence of AR(1) autocorrelation within panels and cross-sectional correlation and heteroskedasticity across panels (Afuah, 2001). Compared with other linear regression models, FGLS estimates are more efficient and hence preferred (Wiggins, 1999). Our model includes year dummies as our hypothesis-testing model does not allow us to specify fixed effects. A potential concern in our choice of FGLS is its ability to control for unobserved heterogeneity and endogeneity in modeling a firm's technology advancement decision. For model robustness we first used a fixed effects model to control for unobserved effects often correlated with the independent variables. Then we excluded the three largest firms from the sample and re-estimated the model. We obtained consistent estimates of the hypothesis testing model.

4. Results

Table 2 reports summary statistics and correlations. The mean Variance Inflation Factor (VIF) is 2.86 and the maximum VIF is 10.10 for total assets. We performed a multicollinearity test and verified the correlations of the estimated coefficients (Echambadi & Hess, 2007). Condition indices of 30–100 generally indicate moderate to strong collinearity. For the variable of total assets there was a condition index of 3.07, assuaging concerns of multicollinearity.

The two proxies for technology advancement, size growth and increase in generation, revealed standard deviations of 0.6 and 0.8, respectively. Though they are equally valid measurements of

[7] The result of a Breusch-Pagan/Cook-Weisberg test for heteroskedasticity is $\lambda_1^2 = 454.66$ (p-value = 0.000), indicating rejection of the null hypothesis that variance is constant. The result of a Wooldridge test for autocorrelation in panel data is F(1, 31) = 71.64 (p-value = 0.000), permitting the rejection of the null hypothesis of no first-order autocorrelation.

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Table 2
Summary Statistics and Correlations

		Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Size growth	0.12	0.52	−0.83	5.88	1														
2	Increase in generation	0.3	0.87	−2.7	7	0.48	1													
3	Market share	0.02	0.05	0	0.93	0.09	0.12	1												
4	Positive financial trend	1.04	3.01	0	23.84	−0.03	−0.10	0.01	1											
5	Negative financial trend	1.2	3.46	0	32.89	0.00	−0.10	−0.02	−0.12	1										
6	Diversification	0.63	0.48	0	1	0.04	−0.02	0.23	−0.03	−0.06	1									
7	Total assets (ln)	10.19	3.51	−0.87	19.13	0.06	0.02	0.06	0.07	0.06	−0.22	1								
8	Total investment (ln)	2.79	2.77	0	8.41	0.22	0.15	0.55	0.01	0.03	0.06	0.23	1							
9	Firm age	6.95	5.14	0	21	−0.05	−0.31	−0.05	0.13	0.13	0.13	0.08	−0.25	1						
10	Licensing w/leader	0.07	0.33	0	4	0.03	0.03	0.17	0.05	0.07	0.03	0.09	0.29	0.00	1					
11	Licensing w/outsider	0.11	0.6	0	8	0.07	0.04	0.18	0.01	0.02	−0.08	0.24	0.28	0.05	0.33	1				
12	Licensing w/laggard	0.11	0.51	0	5	0.20	0.07	0.14	0.10	0.10	−0.07	0.17	0.29	0.04	0.22	0.48	1			
13	Total liability (ln)	9.36	3.75	−1.74	16.93	0.06	0.00	0.09	0.07	0.08	−0.19	0.96	0.24	0.10	0.10	0.24	0.17	1		
14	Above-aspiration performance	0.57	1.14	0	7.11	0.04	0.10	0.43	0.06	0.09	0.14	0.19	0.56	0.06	0.29	0.36	0.31	0.19	1	
15	Below-aspiration performance	0.57	0.64	0	2.3	−0.09	−0.14	−0.33	0.01	−0.03	−0.20	−0.02	−0.55	0.25	−0.16	−0.10	−0.15	−0.09	−0.45	1

technology advancement, it is easier to distinguish small steps from large leaps by first considering the *increase in generation.* The subsample below the 25th percentile represents no advancement; the 25th −75th percentile involves a "small step" of equal to or less than 2 generations, and being above the 75th percentile qualifies as a "big leap" of greater than two generations. The variable *size growth* reveals a similar distribution, confirming considerable variance in the degree of technology advancement. Table 3 presents the statistical results. Models 1–4 use substrate size growth as the dependent variable, while Models 5–8 use the increase in number of generations deployed. Models 1 and 5 contain only the control variables for each dependent variable. Models 2 and 6 include control variables and *above-aspiration performance*; Models 3 and 7 include control variables and *below-aspiration performance*. Models 4 and 8 are full models with all the independent variables. Models 4 and 8 yield consistent predictions on hypothesized effects.

Hypothesis 1 obtained statistical support. *Above-aspiration performance* is negative and significant (β = −0.168, p-value<0.001, Model 4; β = −0.132, p-value<0.001, Model 8), suggesting that on average the degree of technology advancement declines as firms surpass their aspiration level. The negative effect of above-aspiration technological performance on firms' risk behavior is

Table 3
Hypotheses Testing Results

	Size growth				Increase in generations			
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)
Nationality dummy	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
Year dummy	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
Market share	0.130	1.671^{*}	0.0124	1.552^{+}	0.284	1.278^{+}	0.290	1.217
	(0.20)	(2.03)	(0.02)	(1.88)	(0.43)	(1.67)	(0.43)	(1.59)
Above financial aspiration	−0.003	−0.006	−0.002	−0.005	-0.021^{*}	-0.023^{*}	-0.020^{+}	-0.022^{*}
	(-0.38)	(-0.76)	(-0.25)	(-0.67)	(-2.00)	(-2.22)	(-1.92)	(-2.13)
Below financial aspiration	−0.005	−0.007	−0.006	−0.007	-0.015^{*}	-0.016^{*}	-0.016^{*}	-0.017^{**}
	(-0.97)	(-1.38)	(-1.13)	(-1.37)	(-2.34)	(-2.57)	(-2.52)	(-2.68)
Diversification	−0.078	−0.148	-0.186^{+}	-0.219^{*}	−0.115	-0.190^{*}	-0.201^{*}	-0.257^{**}
	(-0.79)	(-1.48)	(-1.76)	(-2.06)	(-1.28)	(-2.11)	(-2.10)	(-2.67)
Total assets (ln)	−0.023	−0.024	−0.020	−0.021	0.016	0.030	−0.014	0.002
	(-1.25)	(-1.16)	(-1.18)	(-1.04)	(0.60)	(1.09)	(-0.50)	(0.08)
Investment (ln)	0.035^{***}	0.081^{***}	0.050^{***}	0.088^{***}	0.024^{*}	0.053^{***}	0.041^{**}	0.065^{***}
	(3.82)	(6.63)	(4.82)	(6.89)	(2.13)	(3.81)	(3.06)	(4.24)
Firm age	−0.008	-0.025^{**}	-0.017^{**}	-0.029^{***}	-0.037^{**}	-0.054^{***}	-0.041^{**}	-0.056^{***}
	(-1.40)	(-3.22)	(-2.69)	(-3.64)	(-2.87)	(-3.75)	(-3.10)	(-3.86)
Licensing w/leader	-0.148^{*}	-0.127^{*}	-0.131^{*}	-0.115^{+}	−0.042	0.001	−0.043	0.0001
	(-2.25)	(-2.01)	(-2.04)	(-1.82)	(-0.61)	(0.02)	(-0.62)	(0.00)
Licensing w/outsider	−0.055	−0.066	-0.072^{+}	-0.079^{+}	-0.076^{+}	-0.084^{*}	-0.085^{*}	-0.092^{*}
	(-1.29)	(-1.54)	(-1.70)	(-1.82)	(-1.95)	(-2.10)	(-2.18)	(-2.30)
Licensing w/laggard	0.096^{*}	0.095^{*}	0.104^{*}	0.102^{*}	0.070^{+}	0.078^{*}	0.067^{+}	0.076^{*}
	(2.27)	(2.32)	(2.51)	(2.50)	(1.88)	(2.05)	(1.78)	(2.00)
Total debt (ln)	0.015	0.022^{*}	0.029^{**}	0.030^{*}	−0.012	−0.019	0.024	0.013
	(1.28)	(1.97)	(2.58)	(2.53)	(-0.58)	(-0.87)	(1.02)	(0.51)
Technological aspiration, above		-0.181^{***}		-0.168^{***}		-0.143^{***}		-0.132^{***}
		(-5.11)		(-4.65)		(-3.67)		(-3.40)
Technological aspiration, below			0.101^{**}	0.076^{+}			0.104^{*}	0.088^{*}
			(3.20)	(1.87)			(2.49)	(2.02)
Observations	350	350	350	350	350	350	350	350
Wald chi-square	119.29	158.57	133.01	162.11	282.51	286.37	280.10	288.55

z statistics in parentheses.
$^{+}p < 0.1$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

analogous to that found in other studies (Miller & Chen, 2004). From margin analysis of Model 4 we can predict that a firm's substrate size growth will decline by an average of 0.17 if the firm is one generation above its technological aspiration level.

Hypothesis 2 garnered statistical support as well. *Below-aspiration performance* is positive and significant ($\beta = 0.076$, p-value<0.1, Model 4; $\beta = 0.088$, p-value<0.05, Model 8), suggesting that the more technological performance falls below the firm's aspiration level, the greater the advance in technology it will undertake. From margin analysis of Model 4 we can predict that a firm's substrate size growth will increase by 0.08 on average if the firm is one generation below its technological aspiration level. The more it falls short of its aspiration level, the bigger the growth in substrate size it will pursue.

We use Model 4 and 8 to interpret results from control variables exhibiting statistical significance above the 95% confidence interval. First, *market share* correlates positively with the degree of technology advancement. A large market share can provide a firm with broader market incentives, leading it to deploy a more advanced technology so as to catch up with new trends in customer demand. Second, both *positive* and *negative financial trend* had a negative effect on the degree of technology advancement measured by increase in generations. We draw the following inferences. Firms with a positive financial trend scale back the degree of advancement to preserve financial resources; firms with a negative financial trend advance less because the costs of advancement jeopardize their financial health. Third, a *diversified firm*'s degree of technology advancement is lesser than that of a specialized manufacturer of panels, probably because the latter is keener on keeping up with the pace of technology advancement to secure its financial lifeline. Diversified firms apparently struggle more with resource allocation than their specialized counterparts since TFT-LCD investments have to vie with other units in the conglomerate for funding. Fourth, a firm's *investment* is positively associated with its likelihood of technology advancement in the coming year. The amount of investment reflects not only a firm's optimism about market demand for more advanced technology but also its financial resources to respond to that demand. Fifth, higher *firm age* reduces the degree of technology advancement. Young firms are more likely to advance by a wider margin. Sixth, a firm having *licensing with leader* has a lower degree of technology advancement and one having *licensing with laggard* has a higher degree on average. The licensing relationship with a leader allows a firm to invest less in R&D because it can rely on the leader to provide technical assistance to counter technological obsolescence. In contrast, a firm engaged in a licensing relationship with laggards has no such leisure and is obliged to maintain a steady pace of R&D investment. Lastly, a positive coefficient for *total debt* suggests that a firm's risk-taking behavior is more aggressive when its financial distress is high, consistent with Ferrier et al. (2002).

5. Discussion

The validation of both hypotheses suggests that firms in the technology race of flat-panel manufacturing are motivated to venture the biggest leaps of technology advancement when their technological aspiration-performance gap is negative and large; they engage in the smallest steps of technology advancement when their aspiration-performance gap is positive and large. The more flat-panel manufacturers trail the pack and see their aspiration-performance gap widen, the *greater* their risk-taking tendency to achieve a high level of technology advancement, consistent with the problemistic search perspective of the BTOF. The more flat-panel manufacturers lead the pack and see their technological performance exceed aspiration levels, the *lesser* their risk-taking effort of technology advancement, contrary to the slack search perspective of the BTOF. Looking forward, it would obviously be useful for future studies to determine whether these results hold for other technology race settings as well.

In particular it would be useful to investigate further whether, as in our study, certain technology races can be considered *technology marathons*. In BTOF terms, a technology marathon can be defined as a technology race in which aspiration levels are social in nature, in which problemistic search governs the behavior of firms with negative aspiration-performance gaps but in which firms with positive aspiration-performance differentials abstain from slack search behavior. The TFT-LCD industry appears to be a technology marathon in this sense. Above-aspiration firms in the industry invest on average the least in technology advancement and thus appear little interested in increasing or even in maintaining their lead and thus outdistancing the pack. In contrast, below-aspiration firms in the industry maintain higher levels of technology advancement and undertake the greatest effort to move closer to the technology frontier. Taken together, these results indicate that participants in the TFT-LCD technology marathon generally tend to converge toward average levels of performance. While contestants make a vigorous effort to avoid falling too far behind in their technology, they also reveal a marked tendency to become less enterprising when they are technologically ahead in the race, consistently willing to allow their technological lead to shrink.

In a technology marathon firms tend to gravitate toward the center of the pack where they are protected from economic and technological headwinds rather than expose themselves to such headwinds by leading or trailing the pack. A technology marathon has different implications for firms above and below the industry average. The leading firms may still pursue technology advancement to compete for the frontier, but the degree of technology advancement striven for is modest. In technology marathons, the benefits of advancement barely outweigh the costs, giving leaders little incentive to be more aggressive in R&D than challengers (Reinganum, 1983). Lagging firms are likely to pursue larger strides to stay in the race.

To our knowledge, the concept of technology marathons has never been developed before. Future work would be required to establish the validity of the concept. In any case, its interest can be demonstrated in reference to other studies. As mentioned above, Lerner (1997) and Lee et al. (2011) were the two main predecessors of the present study in their effort to operationalize technology advancement decisions as a continuous variable. Concerning the phenomenon of technology marathons, however, the similarity ends there. The disk drive industry studied by Lerner (1997) is clearly *not* a technology marathon since, as the author shows, many firms dropped out of the race as the industry consolidated and industry profit margins rose. The industry setting of Lerner had a finish line, in other words, with definitive winners and losers. In contrast, Lee et al. (2011) studied the same TFT-LCD industry as we did, and their conclusions remain broadly consistent with the view of competition in this industry as a never-ending technology marathon: “Market leaders keep investing in new technologies to maintain their leadership, with some turning out to be strategic failures, whereas the followers take risks to catch up with the leaders, often bringing forth technological leapfrogging. A consequence of this technological competition is frequent changes in market leadership” (Lee et al., 2011, p. 720).

Our study is different from but complementary to Lee et al. (2011) in the following ways: first, we explicitly distinguished the technology marathon phenomenon from the technology race perspective and found empirical evidence for it. Second, we employed a behavioral perspective, rather than an economics-based approach, to model the technology marathon aspect of the

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TFT-LCD industry. The behavioral approach allows us to use a social benchmark, i.e., the industry average of technology generations, to predict a technology firm's marathon behavior. Third, our theory postulates the industry average to be a kind of tipping point in the resolve of a firm to advance its technology, while Lee et al. (2011) focus much more on the firm's technological competency as a determinant of its technology advancement. Beyond the tipping point we also found the extent of a firm's technology advancement to be a function of distance from the industry average.

The generalizability of such findings is obviously open to question. Future research would be needed to isolate the specific characteristics of industries harboring technology marathons in contradistinction to technology races with finish lines. Within the TFT-LCD industry itself, more qualitative research on micro-level decision-making processes within firms would clearly be helpful in order to assess the accuracy of the inferences reached mainly on the basis of quantitative industry data analyzed in this study.

6. Conclusion

Motivated to understand why some firms choose to advance their technology aggressively in large leaps while others choose to move forward only in small steps, our study applied the behavioral theory of the firm (BTOF) to the technology advancement decisions of firms in the TFT-LCD industry. By examining the gap between a firm's technological performance and its social aspiration level as a predictor of the degree of technology advancement that firms elect to engage in, our study confirms the explanatory power of the BTOF and especially the problemistic search perspective in cases where firm performance falls below aspiration levels; the greater the gap, the greater the effort and risk firms will take in advancing their technology. In contrast, as expected, the BTOF in general and the slack search perspective in particular was found to have less explanatory power for predicting technology advancement decisions in cases where firm performance exceeds aspiration levels. In order to take account of the asymmetry between above-average and below-average performance impacts, we employed a spline function and a wide array of control variables to isolate behavioral effects.

In contrast to the theoretical eclecticism surrounding most prior analysis of technology races, this study is theory-driven in its application of behaviorist aspiration-performance assumptions (e.g., Giachetti & Lampel, 2010). By operationalizing the concept of problemistic search (Cyert & March 1963) to predict technology advancement decisions, our work complements the capability-based and economic theories usually found in technology management research (Eggers, 2014).

Our study is among the few technology management studies endeavoring to transcend purely binary views of technology advancement decisions, i.e., to advance or not advance. By instead studying the magnitude of such decisions, i.e., by how much a firm chooses to advance, our study helps explain and predict under which conditions a firm will make a “big leap” or merely a “small step.” An obvious question for further research is how applicable our findings are to other high-tech industries where the technology frontier likewise proceeds as a more or less linear sequence of generations and new technologies coexist with old ones, such as in hard disk drives (Christensen, 1997), DRAM chips (Kapoor & Adner, 2012), and semiconductors (Leiblein & Madsen, 2009; Madsen & Leiblein, 2015). Hence we coined the term “technology marathon” to reflect firms’ modest goal of staying abreast but not ahead of the competition.

Obviously our study is limited to a single industry setting, making generalization hazardous. For industries where “winner takes all” is a central feature of competition and innovation, such as those with dominant designs that may drive out alternative technologies, technology marathons may be a less relevant concept. Another arguably idiosyncratic feature of our industry setting is the fairly narrow and continuous technological trajectory of change along stable dimensions. The concept of a technology marathon is clearly less relevant to technological settings characterized by radical discontinuous shifts, e.g., from analog to digital in telephone switches.

Technology advancement decisions are of considerable strategic and economic importance in view of their impact—in competitive positioning and ultimately in profitability—on industries that sell technology-intensive products. Notwithstanding the aforementioned limitations, we believe our study has improved understanding of these vital decisions from a behavioral perspective.

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