No. 023/2020/STR

Keeping Options Alive: Evidence from the Flat Panel Industry

Chang Hyun Kim*

Department of Strategy and Entrepreneurship
China Europe International Business School (CEIBS)

Yong H. Kim

School of Business and Management
Hong Kong University of Science and Technology

Ziyi Chen

School of Business and Management
Hong Kong University of Science and Technology

July 2020

* Corresponding author: Chang Hyun Kim (chkim@ceibs.edu). Address: Department of Strategy and Entrepreneurship, China Europe International Business School (CEIBS), 699 Hongfeng Road, Pudong, Shanghai 201206, China.

KEEPING OPTIONS ALIVE: EVIDENCE FROM THE FLAT PANEL INDUSTRY

ABSTRACT

This study explores how dual investment strategy become effective during technology replacement. To the early entrants of a nascent industry, a dual investment strategy might not be effective. To the late entrants competing at the level of ecosystems, however, dual investments becomes effective. The effect becomes more salient when the firms feature a business group structure and focus on emerging markets as they facilitate managing compounded complexity borne out of maintaining dual options. We find supporting evidence for our theoretical predictions through empirical analyses using 330,774 patents filed in the global flat panel display industry from 1970 to 2010.

Keywords: strategic flexibility; market entry; technological change; innovation and R&D; business groups

KEEPING OPTIONS ALIVE: EVIDENCE FROM THE FLAT PANEL INDUSTRY

INTRODUCTION

When there are multiple technologies competing toward a substitution for old dominant technology, each individual firm must make its own investment choice in advance (e.g., Dosi, 1982; Schilling, 2002; Suarez, 2004). Investment decisions are inherently risky, and this risk becomes further exacerbated by the nonlinear path of technology substitution. Old technologies might reemerge (Raffaelli, 2019), or a seemingly inferior technology might be an eventual winner (Cusumano, Mylonadis & Rosenbloom, 1992; David, 1985). The pattern of technology substitution is also widely heterogeneous across industries (e.g., Adner & Kapoor, 2016). Given this non-linearity of technology substitution processes, a plausible choice is to spread technological bets by investing in multiple technologies at the same time rather than being specialized in a single technology, what we call "dual investment" strategy. By doing so, firms build multiple options with partial commitment across competing technologies (McGrath, 1997; McGrath and Nerkar, 2004). However, empirical studies generally suggest the opposite might be the case (e.g., Eggers, 2012; Klingebiel & Rammer, 2014; Toh & Kim, 2013). For example, managerial costs of maintaining dual options within the boundary of a firm (Eggers, 2012) and switching costs between dual options due to competitive relationship between the dual options (Toh & Kim, 2013) may be the reasons behind the ineffectiveness of dual investment strategy.

This paper aims to reconcile seemingly contradicting theories and equivocal empirical findings by identifying an underlying mechanism by which determines the effectiveness of dual investment strategy. First, we explore how entry timing (i.e., early vs. late) conditions the effectiveness of dual investment strategy. Second, we investigate the moderating effect of organizational forms, specifically business groups often found in emerging economies, on the effectiveness of dual investment strategy. Lastly, we investigate the moderating effect of geographical orientation of organization, specifically emerging market focus. In other words, we examine if and how dual investment strategy can be effective given the uncertainty caused by technology substitution.

Note that in most cases, the substitution of new technology for old dominant technology usually go through discontinuous stages and the rule of games in each stage would be different from each other (Anderson & Tushman, 1990; Greve & Seidel, 2015). At the early stage, the competition is mainly technology-intensive one. Specifically, it is about whether the potential of new alternative technologies can replace the old dominant one. Later, as new demand arises and technological bottlenecks get solved, it becomes a competition between old technology's ecosystem and new technology's ecosystem and a competition between ecosystem of competing new technologies (Adner & Kapoor, 2016). Thus, the uncertainty in the later stage is more socio-complex rather than simple technological one (Raffaelli, 2019).

Our central argument is that the dual investment strategy can help entrants who enter the industry in the late stage characterized by competition between ecosystems in hedging risks and striking a balance between different technologies. However, the strategy would not work for entrants who entered the industry in the early stage characterized by technological competition, as opposed to competition between ecosystems.

Apart from the entry timing, we also investigate whether a business group as an organizational form to coordinate dual technologies within the boundary of a business group, an extended form of a firm. Unlike the risk-hedging effect induced by a diversified financial portfolio, the hedging effect driven by having dual options would not be realized without an appropriate organizational form. We posit that a strong business group structure helps firms overcome the complexity and loosened accountability issues when a firm locates competing technological options under the same ownership roof (Belenzon & Berkovitz, 2010; Knott & Turner, 2019). Therefore, among late entrants using a dual investment strategy, firms affiliated with business groups are more likely to strike an optimal balance between exploiting the dominant technology and exploring other options to respond to potential upheavals between competing technologies.

We test our theoretical predictions in the context of the global flat panel display (FPD) industry. In this industry, multiple technologies have competed to replace a traditional technology. Our analyses of 330,774 FPD-related patents granted to 1,166 firms from 1970 to 2010 show that the effectiveness of dual investment strategy applies for late entrants, but not for early entrants. Furthermore, the impact of investment strategy becomes salient primarily to firms that feature a dominant business group structure, suggesting that firms that are a part of business groups are more likely to pursue multiple objectives beyond the most lucrative option in the short run.

With our core arguments and concomitant empirical findings, we aim to make several theoretical contributions. First, we seek to reconcile conflicting theoretical perspectives on the effectiveness of dual investment strategies. We do this by considering entry timing and industry life cycle simultaneously, while extant research tends to only focus on the early, nascent stage of an industry. In other words, the investigation on effectiveness of initial technology choice (i.e., single vs. dual) should cover the whole substitution process, not an early stage. At the same time, we uncover the cruciality of initial technology choice as an essential part of market entry strategy which has been overlooked in the literature.

Second, extending research on the role of business group in facilitating innovation (Knott, 2001,2002), we highlight the role of business groups in maintaining and capitalizing strategic flexibility under uncertainty inherent technology substitution process and mitigating the potential costs of keeping multiple options. By so doing, we identify a crucial contingency: under technology substitution through competition by multiple technologies, a business group structure with internal business boundaries serves a catalytic role of facilitating innovation. This argument is counter to what is normally assumed in the diversification discount literature wherein business group structure is associated with deterring innovation due to its hierarchical or centralized structure (e.g., Collis & Montgomery, 2004; Rumelt, 1974).

In the section that follows, we present a theoretical framework on how the effectiveness of dual investment strategy varies across industry evolutionary stages (i.e., early vs late). Then, we develop arguments on the roles served by business groups, an effective organizational form coordinating competitive and cooperative relationship between different technology options, in dealing with dual options within the boundary of business group. Next, we develop arguments on the emerging market orientation regarding the effectiveness of dual investment strategy. In the method section, we explain the characteristics of the flat-panel industry and justify the use of the flat-panel industry as the research context of this paper. In the results section, we present our findings and conduct supplementary analyses to ensure the robustness of our key findings. We conclude by discussing the theoretical contributions and practical implications of our research.

THEORY AND HYPOTHESES

Dual Investments and Entry Timing

A nascent industry's evolution is full of uncertainty. One key component of this uncertainty pertains to the rise and fall of dominant technologies. It is hard to predict a priori what technology will win the competition for industry-wide dominance. So much looks similar between how the eventual winning technology and losing technology spread (Greve & Siedel, 2015). Furthermore, it is equally difficult to know how long such dominance can last and when it will end (Adner & Kapoor, 2016). Nevertheless, firms' strategic choices at the time of entry, such as technology choice at the time of entry and entry timing, have a long-lasting impact to firms due to their path-dependency (Greve, 2009; Klepper & Graddy, 1990) as well as the irreversibility of their physical investments (Ghemawat, 1991; Ghemawat & Sol, 1998).

Given the importance of firms' strategic choice at the time of entry and dynamics of technology substitution process, one reasonable, intuitive resolution would be maintaining strategic flexibility by widening the breadth of the initial technology choice. By doing so, firms can spread the risk by allocating their investment in a diverse range of projects and then selecting the more prominent ones as uncertainty reduces (e.g., Trigeorgis & Reuer, 2017). Firms would amplify subsequent innovation performance by focusing on promising project and selecting out unpromising project as uncertainty dissipates (Klingebiel & Rammer, 2014). Moreover, firms would protect themselves from the curse of path dependency and prepare themselves against various scenarios in the future.

In this paper, we argue that the benefits of broadening initial technology choice are primarily reserved for late entrants, as opposed to early entrants for three reasons. First, in the early stage of technology substitution process, a high level of uncertainty in terms of which technology will eventually prevail naturally breeds a so-called "legitimacy vacuum," a condition in which clarity about the form and function of the new technology as a category is lacking (Dobrev & Gotsopoulos, 2010: 1153). Compared with late entrants, early entrants are fully immersed in the legitimacy vacuum. Hence, they need to build new knowledge through trial-and-error learning with little prior experience, which incurs more explorative costs especially when the firms develop multiple technologies at the same time (Bingham & Davis, 2012). Moreover, under the legitimacy vacuum, such explorative behavior exhibits a sign of less confidence in a new technology to crucial gatekeepers such as venture capitalists or internal budget controllers, who make the funding decision for the new technologies. As the legitimacy vacuum dissipates, late entrants can take advantage of mistakes and errors from early entrants to solve technological problems or navigate through market uncertainty (Kerin, Varadarajan, & Peterson, 1992; Lieberman & Montgomery, 1988). They can also harness early entrants' investments and filter out anything that is no longer relevant or useful (cf. Benner, 2007; Doh, 2000). Therefore, late movers' vicarious learning advantages make the exploration cost lower than that of early entrants when they develop multiple options together.

Second, in the early stage of technology substitution process, the whole industry focuses on the product innovation while in the late stage on the process innovation. In this race of product innovation, firms strive to be 'the first' by enhancing learning speed (Rothaermel, 2016). A firm which presents a new prototype or product which materializes and validates its technological superiority against the old dominant technology for the first time would enjoy the reputation of the first mover (Lieberman & Montgomery, 1988). Due to the cruciality of the speed in the race of product innovation, much less emphasis is put on manufacturability or marketability. In this race in the early stage, the strategic flexibility endowed by dual investments would not reap much benefit. Most of all, the breadth of initial technology choice has a detrimental impact on learning speed due to its dispersed attention to each option (Barnett, Greve & Park, 1994). Furthermore, only followers adapt to a more prominent option by switch between options. In other words, adaptive switch to a more prominent technology means the second at best. Therefore, prior literature focusing on the competitive landscape of early stage often recommends commitment to a technology to be the first rather than strategic flexibility through dual investments (Toh & Kim, 2013).

In the late stage, however, the competition becomes more non-linear and socio complex. The performance at consumer markets often determines the winner. To ensure such marketability, it becomes critical to construct an eco-system which embraces complementary assets and goods which ensure the quality of the whole consumer experience. The competition between each technology's ecosystem, as opposed to an isolated core technology, facilitates diverse forms of collaboration across value-chain and even among competitors (Cui & Connor, 2012; Soda, 2011). Under such circumstances, each ecosystem proactively encourages other firms to shift to their ecosystem at better terms and conditions to maximize economies of scale and network externalities (Tushman & Anderson, 1986). To achieve these goals, firms often construct patent pools to make the licensing process time short and cost effective (Joshi & Nerkar, 2011) or form multiple partnerships to achieve a shared objective (Soh, 2010). By doing so, they increase the chance of winning against another ecosystem.

Due to the non-linearity and socio complexity of the competition at the level of eco-system, we often find a significant discrepancy between value-creation and value-capture (Pisano, 2006; Teece, 1986) in the technology substitution process. The complexity in this stage often ends up with unexpected outcome, such as winning by inferior technology or upheaval between late and early movers. We argue that the evolution from competition between core technologies to between ecosystems creates room for adaptation (Adner & Kapoor, 2016) and thus firms with strategic flexibility due to the breadth of initial technology choice are more likely to catch such opportunities. Hence, making the dual investment strategy become more effective to later entrants. While in early stage dual investments strategy delivers a signal of less confidence and weak commitment to be the first, in late stage the same strategy offers a room for late entrant's agile adaptation.

Last but not the least, as the substitution process evolves, the option value of dual investment also increases (Folta & Miller, 2002). In the early stage of a nascent industry, in general, there are multiple core technologies competing to replace the old technologies. In such circumstances, having more than one option did not provide a concrete insurance effect, because duality covers only part of uncertain future scenarios. In later stage when main ecosystems compete for sole dominance; however, dual investments have a clear strategic ramification, almost covering plausible future scenarios. Given the dynamics of industry evolution and option value, we predict:

> Hypothesis 1. Late entrants that enter with both the winning and initially losing technologies will exhibit faster subsequent knowledge growth.

Organizational Form for Late Entrants: Business Groups

The pursuit of strategic flexibility by locating competing solutions within the boundary of a firm also creates managerial issues, such as coordination and control (Eggers, 2012). Most of all, the amount of attention given to each solution would be less than the case where a firm has one option. Rather than overcoming crucial but essential hurdles, they might turn their attention to another option not to face the hurdles. Furthermore, due to the competitive relationship between competing solutions (Dosi, 1982; Suarez, 2004), knowledge sharing across such solutions would be limited even though the two options are located under the same ownership roof. Even when the firms succeeded in sharing knowledge across internal boundaries, such knowledge sharing creates another problem. Knowledge sharing across two competitive solutions hampers competitive spirit between competing units and blurs accountability of each unit. For example, an internal unit might claim some credits of the performance of the other internal unit because they shared information critical to improve performance of the other unit. In other words, collaborations across competing units make it difficult to observe and evaluate the performance of each unit. Therefore, the actual contribution made by each unit to the total value created, often lose their direct causality (Larkin2014; Pierce, 2012). From the perspective of traditional agency theory, the loosened coupling due to blurred accountability might bring a weak sense of urgency, leading to shirking or free-riding (Hennart, 1993).

Given these constraints, we expect a dominant business group structure, as an alternative organizational form, to serve its role as a solution to resolve the complex coordination between competing technologies and loosened accountability issues caused by keeping dual options alive within the same organization. According to the traditional view on innovation, adding another layer of hierarchy, such as corporate headquarters often found in a business group, is antithetical in a nascent industry characterized by a dynamic and innovative nature (Burns & Stalker, 1961). An organic structure, characterized by flatness, decentralized decision making, and agility due to the small number of layers has been suggested as an ideal organizational form for a nascent industry, as opposed to a bureaucratic structure. The business group structure has been characterized by formality, centralized decision making, and bureaucracy. Based on such rigidity, conglomerates or business groups often fail to become strong competitors in a dynamic nascent industry (Christensen, 1997; Christensen & Raynor, 2003; Lange, Boive & Henderson, 2009).

Inspired by classic literature on 'M-form' organization (Chandler, 1990; Williamson, 1975) and recent theoretical developments on the role served by a business group in innovation (Belenzon & Berkovitz, 2010; Knott & Turner, 2019), we expect the business group structure to resolve the coordination and accountability issues caused by dual investments in competing technologies. Theoretically, positive effects of the business group on innovation and growth mainly stem from the role served by corporate headquarters and an internal division of labor. A corporate headquarter establishes routines and processes which govern inter-unit's competition and cooperation that fuels innovation and growth. Social comparison between inter-units and subsequent peer pressure intensifies internal competition and the intervention of corporate headquarters as an institutionalized organizational code stimulates systematic coordination without hampering accountability of each unit (Birkinshaw & Lingblad, 2005; Hu, He, Blettner & Bettis, 2017; Kacpercyzk, Beckman & Moliterno, 2015). Combined with the competitive nature of dual solutions (Schilling, 2002), intensified internal competition expedites the learning speed of each inter-unit that is in charge of a solution.

Regarding the internal division of labor within a business group, prior literature highlights the division of labor between corporate headquarters and operational units (March & Simon, 1958; Nelson & Winter, 1982). While operational units focus on efficiency, corporate headquarters focus on innovation and strategy (Knott, 2001, 2002). By doing so, a business group is more likely to strike a good balance between exploration and exploitation (March, 1991). Each subsidiary focuses on a technology and takes full responsibility for the selected technology. Furthermore, one subsidiary competes against the other subsidiary focusing on another technology internally. Due to the internal firm boundary between inter-units (Knott &Turner, 2019), accountability and sense of urgency of each intra-unit would not be dampened by having dual options within the boundary of a business group. Knowledge sharing is orchestrated through the intervention by corporate headquarters through monthly/quarterly performance reviews or peer reports. This type of sharing across intra-units intensifies accountability of each intra-unit rather than weakens it (Song, Lee &Khanna, 2016). Functional organization in a single-business firm, as opposed to M-form, would not provide such benefits (Chandler, 1990). Taken together, we predict:

> Hypothesis 2. The positive effect of dual investments by late entrants is more salient when dual investments are made by late entrants with a business group structure.

Emerging markets

Apart from the internal coordination and control issues, the value of strategic flexibility is also likely contingent on the geographic environment in which firms are located. With the rise of emerging markets in economic growth and technological development, we expect that among late entrants with dual technological investments, firms with a greater focus on emerging markets would generate more innovation for two reasons.

First, emerging markets are typically characterized by rapid changes, under which the gains from strategic flexibility tends to be maximal. There is a long-standing literature theorizing and documenting that while flexibility involves efficiency costs, it helps firms better respond and adapt to changing market environments (e.g., Beach, Muhlemann, Price, Paterson, & Sharp, 2000; Claussen, Kretschmer, & Stieglitz, 2015; Grewal & Tansuhaj, 2001; Nadkarni & Narayanan, 2007). Therefore, environmental volatility increased the option value of strategic flexibility. In other words, in a stable environment, it incurs unnecessary additional costs to maintain strategic flexibility by keeping dual options. It is well recognized in the international business literature that emerging markets exhibit a faster rate of change in various dimensions such as industry structure, technologies, consumer preferences, institutions, etc. (e.g. Luo, 2007). For firms with dual technological investments, emerging economies provides contingencies that facilitate exercising real options because they can capitalize on such market uncertainty and make the best use of their different technological capabilities in creative ways (Aabo, Pantzalis & Park, 2016).

Different preferences to a new product and slow adoption rate of new technology often found in emerging markets also make it possible for firms having dual technologies including the initially inferior technology in advance economies to identify market potential in emerging markets.

Second, after firms' decisions to invest in dual technologies to maintain flexibility, patenting in emerging markets can help firms minimize the costs associated with those investments and create value for future innovation. Filing patents in emerging markets incurs substantial costs and requires considerable time in the application and examination process (Huang & Li, 2019). As a result, patents granted in emerging markets are often viewed as strong signals of technological capabilities in those countries. As pointed out by Hu (2010), such signals can pose serious threat on competitors' entry decisions. The reduced competition intensity can greatly mitigate the competitive disadvantages of firms with dual investments due to dispersed resources. In addition, those signals can attract valuable resources such as government subsidy as well as local collaborators, which are critical for firms' subsequent technological development (Keupp, Friesike, & von Zedtwitz, 2012).[1] Therefore, we hypothesize that:

> Hypothesis 3. The positive effect of dual investments by late entrants is more salient when the firm has a stronger focus on emerging markets.

CONTEXT: LCD'S INITIAL DOMINANCE AND PDP's REEMERGENCE IN THE GLOBAL FPD INDUSTRY

Our empirical context is the global flat panel display industry. Before the emergence of the flat panel technology, cathode-ray tube (CRT) was the dominant technology in making screens. The problem with the CRT was that as the screen's size increases, the screen also became thicker proportionally, making large-size screens extremely bulky. To produce flat and thin displays with comparable full-color images, several flat panel technologies emerged in the 1970s, such as liquid crystal display (LCD), plasma display panel (PDP), electroluminescent display (ELD), etc. The focus in the early stage of the FPD industry was which specific technology could match the performance of a CRT.

In the early 1980s, several technological breakthroughs made LCD more appealing for developing flat panels. In particular, Seiko Epson succeeded in producing the first full-color LCD prototype in 1983, which showed the great potential of LCD in making flat panels. Moreover, LCD enjoyed many other advantages over other FPD technologies, including the thinnest profile, the lightest weight, the lowest power requirement, and the lowest cost (Tannas Jr, 1994). Thus, the attention of firms in this industry became how to fully realize the potential of LCD and make it into mass production (Eggers, 2012). At that time, not surprisingly, PDP and other flat display technologies were deemed “niche markets” (Wong and Matthews, 1998).

However, in the mid-1990s, PDP became a “hot” technology primarily due to its capacity to handle large screens. LCD was still widely used, but its weakness in making large (i.e., 40-inch or wider) displays became apparent with the ever-growing demand for large-screen televisions. As a result, many firms started to actively invest in research and development related to PDP technology. As shown in Figure 1 where we visualize the annual count of LCD and PDP patents, LCD was the dominant technology in the FPD industry in its early stage, but invention in PDP (re-)emerged in the mid-1990s. Advancements in PDP technology led to more products and more sales. For example, Fujitsu introduced the world’s first 42-inch plasma television in 1995 and began mass production in the following year. PDP captured over 70% of the market share in the above-40-inch flat television market since 2005 (CNET, 2006).

[Figure 1 goes about here]

The FDP industry features three aspects that are relevant to our theory and hypotheses. First, the FPD industry is highly technology-intensive, and characterized by slow substitution process with persistent technological and market uncertainty. Technology choice at entry is thus a crucial strategic decision for firms. Second, this industry has significant entry barriers and requires substantial costs in developing competitive advantages of key technologies. Thus, business groups might gain considerable advantages in this industry. Finally, the FPD industry is featured with fierce global competition, which highlights the value of strategic flexibility. Firms from the US, Japan and Korea have been the major players in this industry, and more recently, firms from emerging markets such as China are playing an increasingly important role. The global competition combined with the technological landscape requires firms to actively respond to the latest market changes. Accordingly, our empirical analyses focus on 1,166 firms' patenting activities in the global FPD industry from 1970 to 2010.

DATA AND METHODS

Dependent Variables

We used two patent-based variables to measure the performance of knowledge creation, because those patents are firms' key sources of competitive advantages and future financial returns. Our first dependent variable, LCD patents, counted the number of LCD patents that a firm applied for in a given year.[2] The second dependent variable, PDP patents, was measured as the number of PDP patents that a firm applied for each year, which captures a firm's ability to identify the rising niche market and keep updated on the latest technology.[3] We obtained patent data from Clarivate's Derwent Innovation Index, a data source widely used in prior research on firm innovation (e.g., Doblinger, Surana, & Anadon, 2019; Parente, Melo, Andrews, Kumaraswamy, & Vasconcelos, 2020; Potter & Wilhelm, 2019).[4]

Independent Variables

Due to the breakthrough by Seiko and subsequent industry trend toward LCD mentioned in context section and following prior literature (Eggers, 2012), we categorize the firms which entered FPD before 1983 as early entrants and the others as late entrants. Regarding initial technology choice, we created three binary explanatory variables that correspond to three types of technology choices at market entry: entering with LCD, PDP, or both of them. To construct these variables, we first computed the ratios of LCD and PDP patents to all flat panel patents in a firm's first five years in the industry, respectively. Following Eggers (2012), a firm is defined as entering with LCD if the ratio of LCD patents at entry is more than 80%, entering with PDP if the ratio of PDP patents at entry is more than 80%, and entering with both if the two ratios are below 80%. In our sample, 83% of late entrants entered with LCD, 5% with PDP, and 13% entered with both technologies. Figure 2 shows firms' technology choice at entry by their entry years. Additionally, we found no evidence for an association between a firm's entry timing and its propensity to use dual investment strategy ($chi^2 = 0.478$, $p = 0.490$, $d.f. = 1$).

[Figure 2 goes about here]

The strength of business group structure was measured based on the number of subsidiaries that have been granted LCD or PDP patents. There exists no common, international database of group affiliations (Khanna & Rivkin, 2001), and thus we use one feature of a business group that is common across the globe – a business group is a confederation of firms – as the basis to proxy the strength of business groups. Specifically, we sorted the firms with more than one subsidiary in each year, and defined a firm as having a strong business group structure if the number of subsidiaries is above the median of the annual cohort, and as having a weak business group structure otherwise. We also created a separate binary variable, independent firm, for firms that do not have any subsidiary, and they account for about half of firms in our sample. A firm's focus on emerging markets was measured as the proportion of patents that were granted in countries defined as emerging economies by the International Monetary Fund (IMF).[5]

Control Variables

To ensure the robustness of our results, we incorporated a set of control variables to account for firms' past knowledge creation activities, the features of inter-firm collaboration in patenting, geographical foci and firm size. All of these variables could potentially affect firms' knowledge creation in LCD and PDP technologies.

We first control for the existing stocks of a firm's LCD and PDP patents. Two variables, (log) LCD patent stocks and (log) PDP patent stocks, account for the possibility that the accumulated knowledge in those technologies may persistently influence how the firm allocates resources and chooses future directions. Given that some inventions can be categorized into multiple technologies, we controlled for the stock of a firm's (log) general patent stocks, measured as the cumulative number of patents that are classified as both LCD and PDP technologies. To account for alternative pathways for firms to combine resources and explore other potential technology options, we incorporated a binary variable, alliance, which takes the value of 1 if the focal firm has had any FPD patent co-developed with another firm. We excluded all instances of alliances between two of more firms affiliated with the same business group. Apart from emerging economies, firms can also file patents in other areas of the world and some international organizations. We thus controlled for the proportion of a firm's patents filed and granted in the major markets of the FPD industry (i.e. the U.S., Japan, and Korea), and use the proportion of patents elsewhere as the reference category. Finally, we proxied firm size with a dummy variable indicating whether the firm has been on the Fortune Global 500 List.

Analyses

We hypothesized that a dual investment strategy is better for late entrants than a single investment strategy, and that such benefits are more salient among firms with a strong business group structure or with an emerging market focus. To formally test our hypotheses, we used generalized estimating equation (GEE) negative binomial model with a first-order autoregressive correlation structure (AR1). GEE models are suitable for controlling for the unobserved firm-level heterogeneity because it provides population-average coefficients (Echambadi, Campbell, & Agarwal, 2006: 1810).[6]

RESULTS

Table A1 in Online Appendix A displays the descriptive statistics and zero-order correlations for all variables. Low values of both variance inflation factors (ranging from 1.08 to 5.06) and condition indices (ranging from 1.00 to 5.72) indicate that multicollinearity is unlikely to impact our estimates.

Hypothesis 1 predicted that late entrants that enter with both technologies (i.e., both LCD and PDP) tend to be more successful than late entrants entering with a single technology (i.e., either LCD or PDP).[7] In Model 1a and 1b of Table 1, we first ran the analysis in the sample of both early and late entrants. The coefficient on entering with both in the LCD patenting model is negative and significant at the 10% level, and there is no significant difference between the coefficient on entering with both and that on entering with PDP in the PDP patenting model. The results suggest that when pooling early and late entrants together, we do not find evidence that firms using the dual investment strategy perform better. In Models 2a – 4b, we focused on late entrants. Consistent with H1, Models 2a and 2b of Table 1 show that firms entering with both technologies achieve a better balance between LCD and PDP. Specifically, compared with firms entering with only LCD, firms entering with both technologies tend to develop more PDP patents after the reemergence of PDP ($b=0.310$, $p<0.001$, Model 2b), and do not show worse performance in developing LCD patents either ($b=-0.001$, $p=0.986$, Model 2a). Moreover, compared with firms entering with only PDP, firms that enter with both technologies obtain more LCD patents (b=-0.001 vs b=-0.542, p<0.001, Model 2a), and do not underperform in developing PDP patents either (b=0.310 vs b=0.354, p=0.684, Model 2b). In terms of the magnitude of the reported effects, firms that entered the FPD industry with both technologies have 0.61 more LCD patents per year than firms that entered with only PDP, and 0.08 more PDP patents than firms entering with only LCD.[8] Please note that the magnitude is calculated annual base. Given the slow substitution process in FPD, the accumulated magnitude over the multiple years is quite significant in its economic impact. Moreover, in our sample, more than half of the firm-year observations have zero patent per year. The number shows the importance of a patent in FPD industry.

In Hypothesis 2, we argued that among late entrants entering with dual technological investments, firms with a strong business group structure would outperform those with a weak business group structure. In Models 3a and 3b of Table 1, we added the interaction terms between strong business group structure and the indicators of technology choices at entry. We find that H2 is supported in the LCD patenting model, but not in the PDP patenting model. Specifically, when the dependent variable is the annual count of LCD patents, the coefficient on the interaction between entering with both and strong business group structure is positive and significant at the 10% level (b=0.190, p=0.073, Model 3a). In Model 3b where the dependent variable is the annual count of PDP patents, the coefficient of that interaction term is insignificant. One potential reason might be that compared with PDP, LCD development requires more intensive capital investments at the beginning (Castellano, 1992), so the support from business groups matters more in LCD patenting. Therefore, H2 is partially supported.

Hypothesis 3 suggested that among late entrants entering with both LCD and PDP technologies, firm with a stronger focus on emerging markets would exhibit faster knowledge growth than those with less focus on emerging markets. To test this hypothesis, we added in Models 4a and 4b the interactions between presence in emerging markets and the indicators of technology choices at entry. Consistent with H3, the interaction terms are positive and significant at $\alpha = 0.01$ level (b=0.438, p<0.001, Model 4a;

b=0.299, p<0.001, Model 4b). Figure 3 plots the estimated number of patents of firms with different technology choices at entry, organizational structure and geographical foci.

[Table 1 and Figure 3 go about here]

SUPPLEMENTARY ANALYSES[9]

The degree of market uncertainty

As discussed earlier, for late entrants in the flat panel industry, the period before the reemergence of PDP is more uncertain than the period afterwards. If our theory on risk hedging is correct, our hypothesized effects would be stronger among firms entering before the reemergence of PDP. To test this conjecture, we divided late entrants into two groups: those entering between 1983 and 1990 and those entering after 1990, and re-ran the same analyses in the two subsamples separately.

Table 2 presents the split-sample regression results. In the sample of late entrants entering before the reemergence of PDP, the coefficient on entering with both is positive and significant in the PDP patenting model (b=0.332, p<0.001, Model 5b), and significantly greater than that on entering with PDP in the LCD patenting model (b=0.100 vs b=-0.385, p<0.001, Model 5a). The results suggest that among those firms, dual investment strategy is indeed more effective than single investment strategy. The moderating effect of business groups also become stronger (b=0.249, p=0.033, Model 6a). However, in the sample of firms entering after the reemergence of PDP, while the coefficient on entering with both is still positive and significant, it is significantly smaller than that on entering with PDP (b=0.341 vs b=0.899, p=0.002, Model 7b). Furthermore, the moderating effect of strong business group structure is no longer positive and even turns significantly negative in Model 8b. Taken together, our findings support the view that the dual investment strategy is more effective when the entrants face greater uncertainty.

[Table 2 goes about here]

DISCUSSION

In this paper, we examine the consequence of firms' initial technology choices among multiple competing technologies in a technology-intensive industry. Specifically, given the substantial and ongoing uncertainty in the industry, we ask when spreading the technology focus will pay off. Our principal argument is that the effectiveness of such a dual investment strategy is contingent upon the external environment when the firm first entered the industry, the organizational structure of the firm and the geographical foci of the firm. Our study produced three key findings.

First, dual investment strategy is more effective for late entrants than it is for early entrants, because late entrants were faced with less legitimacy pressure. As a result, such late entrants that employ dual investment strategy can better deal with the emergence of unexpected facets during non-linear technology substitution process. Our empirical findings show that late entrants that enter the flat panel display industry with both LCD and PDP technologies strike a better balance between the two technologies than those entering with a single technology. The opposite is true, however, for early entrants.

Our second key finding is that a business group structure helps late entrants coordinate competing technologies within the boundary of a firm. Specifically, among late entrants with dual investments, firms with a strong business group structure outperform those with a weak business group structure. Lastly, we find that a stronger focus in emerging markets enables late entrants with a dual investment strategy to achieve greater innovation outputs in both technologies they initially invested into.

Contributions and Limitations

This study makes several key contributions. First, we bridge the real option theory which emphasizes the benefits of keeping strategic flexibility (McGrath, 1997; McGrath &Nerkar, 2004) and the resource partitioning literature which suggests the issue of poor learning and difficult coordination in generalist firms (Barnett et. al, 1994; Haunschild & Sullivan, 2002). Both theories focus on the costs or benefits of dual investments within the boundary of the firm, but overlook the cruciality of entry timing, early or late entrance. Different entry timing means different external environment conditions, which is of vital importance to the new entrants (Dobrev & Gotsopoulos, 2010). Thus, building on the structural imprinting perspective, we argue that the environment uncertainty when the firm first entered the industry would be an important boundary condition. Furthermore, unlike previous studies which tend to look at only core technology uncertainty (Eggers, 2012; Toh & Kim, 2013), we contend that there are different types of uncertainty at various stages of an industry. As a core technology shows its technological prowess in replacing old technology, the competition between each ecosystem emerges (Adner & Kapoor, 2016). Competition at the level of ecosystem lays favorable conditions by which entrants with a dual investment strategy would shift their focus from winning to losing technology, or vice versa, with a low switching cost. Therefore, our study not only reconciles the different viewpoints regarding multiple technology investment, but also adds a more dynamic and comprehensive perspective to the existing theories. Such extension would also help us reevaluate the benefits of real options.

Second, we address the potential costs of keeping multiple options by highlighting the unique role of business groups in managing different technologies under uncertainty. Coordination under uncertainty and complexity have been salient issues in the research of generalist versus specialist organizations (e.g., Haunschild & Sullivan, 2002). Based upon the organizational structure literature, we theorize that business groups can be an alternative form to deal with such issues within the boundary of a firm. On the one hand, the corporate headquarter can handle heterogeneous facets emerging throughout the non-linear technology substitution process by allocating a technology option to each subsidiary and facilitating intra-unit knowledge sharing and intensifying intra-unit competition at the same time. At the level of business group, however, the group can strike an optimal balance between competing technologies and thus achieve greater flexibility to cope with uncertainty. Hence, our study also speaks to a broader literature on organizational ambidexterity (Raisch & Birkinshaw, 2008) and the classical discussion on exploration versus exploitation (March, 1991).

Third, our study also contributes to the business group literature itself. Innovation within business groups has been of considerable scholarly interest in this field, and prior literature documents that business groups can promote innovation by constructing an internal capital market and compensating for the weak national institutional infrastructure (Belenzon & Berkovi, 2010; Chang, Chung, & Mahmood, 2006). We build on this stream of literature by adding more evidence on the positive influence of business groups on innovation and showing another mechanism, namely allowing for strategic flexibility at the context of technology substitution by multiple technologies. This perspective would be of more importance given the fast-evolving technology landscapes and the increasingly volatile, uncertain, complex and ambiguous (VUCA) environment. Furthermore, our research combines the business group perspective with the notion of environment characteristics. Unlike previous literature which devalues the value-creation role of business groups in turbulent environments (Mahmood, Zhu, & Zaheer, 2017), our study emphasizes the value of business groups under uncertainty and thus provides a more complete picture on how the influence of business groups interact with external environments.

Our research also offers managerial implications to practitioners. Conventional wisdom suggests that when confronted with multiple alternatives, the best way to hedge the potential risk is investing in both options. Yet, prior literature provides theoretical justifications and empirical evidence both for and against this conjecture. Then how should a firm choose when entering an industry with competing technologies? We reconcile such tension by combining entry timing, early vs. late, and initial technology choice, single vs double investments. Managers should consider two aspects when making their entry decisions. For early entrants, technology uncertainty dominates at the time, so entering with both technologies may prevent firms from showing commitment to the gate keepers and dilute the firm's resources in winning the technology race during the crucial early period. But for firms that are late to the industry, it is important to realize that the locus of competition shifted from core technology to ecosystem. Hence, keeping both technologies in hand allows rooms to maximize late entrant's adaptational advantages without being trapped into the peril of path dependence, fixing to initial choice. Moreover, those firms need to have a business group structure and the capabilities to coordinate different technologies and allow for the exploration and exploitation by its semi-independent affiliates.

Future Research Directions

Our research design does not explicitly compare between new startups and corporate diversifiers into this industry. With more information on the pre-entry characteristics (Moeen, 2017), future studies can examine how the effect of dual investment strategy varies between those two types of entrants. It is also curious how new startup entrants could manage to survive in this industry. The history of the flat panel industry has witnessed numerous collaborations and corporate restructuring events such as mergers, acquisitions, and spinoffs. Those anecdotal evidence suggests that finding a unique niche market and cooperating with the giants might be an effective strategy. Future research might look deeper into these issues.

As the technology advances in the flat panel industry, other new technical solutions have been emerging as well, such as organic light-emitting diode (OLED). When faced with the new uncertainty, it would be interesting to test whether our theory on new entrants' technology choice can still hold in this more recent context. Yet, those new entrants are now faced with far more intense competition against the giant incumbent firms, most of which are business groups. The competition dynamics may further complicate the issue of technology choice for those entrants. More broadly, the phenomenon of competing technologies in one field have been more and more common in today's world and the issue of choosing between those technologies under uncertainty and resource constraints is pervasive. It is thus meaningful to examine the generalizability of our theory across different contexts.

Appendix A.

Panel A. Variable definitions and summary statistics

	Variable name	Definitions
1	Annual count of LCD patents	Number of LCD patents a firm applied for each year
2	Annual count of PDP patents	Number of PDP patents a firm applied for each year
3	Enter with both	A dummy variable equal 1 if the proportion of LCD and PDP patents during the first 5 years since entry are below 80%, and 0 otherwise.
4	Enter with PDP	A dummy variable equal 1 if the proportion of PDP patents during the first 5 years since entry is above 80%, and 0 otherwise.
5	Strong business group structure	A dummy variable equal 1 if the number of subsidiaries is above the median number of subsidiaries of firms each year, and 0 otherwise.
6	Focus on emerging markets	Proportion of patents that are granted in countries in countries defined as emerging economies by the IMF.
7	LCD patent stock	Natural log of the total number of LCD patents since entry.
8	PDP patent stock	Natural log of the total number of PDP patents since entry.
9	General FPD patent stock	Natural log of the total number of patents that are classified as both LCD and PDP technologies.
10	Alliance	A dummy variable equal 1 if the firm has had any FPD patent co-developed with another firm, and 0 otherwise. Alliances between two or more firms affiliated with the same business group are excluded.
11	Focus on major FPD markets	Proportion of patents that are granted in the US, Japan and Korea.
12	Independent firms	A dummy variable equal 1 if the firm does not have any subsidiary, and 0 otherwise.
13	Fortune Global 500	A dummy variable equal 1 if the firm has been on the Fortune Global 500 List, and 0 otherwise.

NOTES

[1]One might argue that weak intellectual property rights protection in emerging economies may discourage firms from patenting in those countries and reduce the value of those patenting activities. However, the number of patents filed and granted in emerging markets by foreign firms has surged during the past few decades. In addition, despite the generally weak appropriability regimes, the literature suggests that foreign firms have developed various tactics to achieve de facto protection (e.g. Keupp, Beckenbauer and Gassmann, 2010).

[2]To ensure the quality of the patents, we only consider LCD or PDP patents that are eventually granted.

[3]We measure this variable during the period between 1991 and 2010, because the PDP technology reemerged only after the 1990s. Further note that around 37% of the firms do not have any PDP patents during that period, and the number of PDP patents equals zero for 73% of the firm-year observations in our sample. Thus, as a robustness check, we use a binary variable to capture whether a firm has any PDP patent in a given year, and estimate the regression equation with the probit model. The results remain qualitatively similar.

[4]From an initial sample of 330,779 FDP-related patent families, we removed patents assigned to an individual or a non-corporate entity. We also dropped firm assignees that had fewer than four patents during their entire life span.

[5]These countries are: Brazil, China, Hungary, India, Malaysia, Mexico, Philippines, Poland, Romania, Russia, Thailand, and South Africa.

[6]We are unable to run (firm) fixed effects models, because our key independent variables' values (market entry choice made by a firm) do not vary within a firm.

[7]One assumption behind this argument is that dual investment strategy is not a good entry choice for early entrants (e.g., Eggers, 2012). We empirically test and find support for this assumption. In Appendix B, we classified firms into 6 categories based on their entry timing (early or late) and technology choice at entry (entering with LCD, PDP or both), and use early entrants entering with both as the reference group.

We find that early entrants that entered with both technologies have significantly worse performance in both LCD and PDP patenting than early entrants entering with the initially winning technology. Furthermore, they also do not outperform late entrants entering with both technologies, either.

[8]We used the point estimates from Models 2a and 2b of table 1 to calculate the marginal effects of entering with both on LCD and PDP patenting. All control variables were kept at their mean values for these calculations.

[9]We check the robustness of our main findings and supplementary analyses in a number of ways, including using a binary variable indicating PDP patents as the dependent variable, combining firms entering with either LCD or PDP into one group, and changing the cutoff year of the reemergence of PDP. The results are similar, and for brevity, we do not report them in the main texts.

REFERENCES

Aabo, T., Pantzalis, C. & Park, J.C. 2016. Multinationality as real option facilitator—Illusion or reality?. *Journal of Corporate Finance*, 38: 1-17.

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

Anderson, P., & Tushman, M. L. 1990. Technological discontinuities and dominant designs: A cyclical model of technological change. *Administrative Science Quarterly*, 35(4): 604-633.

Barnett, W. P., Greve, H. R., & Park, D. Y. 1994. An evolutionary model of organizational performance. *Strategic Management Journal*, 15(S1): 11-28.

Beach, R., Muhlemann, A. P., Price, D. H., Paterson, A., & Sharp, J. A. 2000. A review of manufacturing flexibility. *European Journal of Operational Research*, 122(1): 41-57.

Belenzon, S., & Berkovitz, T. 2010. Innovation in business groups. *Management Science*, 56(3): 519-535.

Benner, M. J. 2007. The incumbent discount: Stock market categories and response to radical technological change. *Academy of Management Review*, 32(3): 703-720.

Bingham, C. B., & Davis, J. P. 2012. Learning sequences: Their existence, effect, and evolution. *Academy of Management Journal*, 55(3): 611-641.

Birkinshaw, J., & Lingblad, M. 2005. Intrafirm competition and charter evolution in the multibusiness firm. *Organization Science*, 16(6): 674-686.

Burns, T., & Stalker, G. M. 1961. *The management of innovation*. London: Tavistock.

Chandler, A. D. 1990. *Strategy and structure: Chapters in the history of the industrial enterprise (Vol. 120)*. MIT press.

Chang, S. J., Chung, C. N., & Mahmood, I. P. 2006. When and how does business group affiliation promote firm innovation? A tale of two emerging economies. *Organization Science*, 17(5): 637-656.

Christensen, C. M. 1997. *When new technologies cause great firms to fail*. Harvard Business Review Press.

Christensen, C. M., & Raynor, M. E. 2003. Why hard-nosed executives should care about management theory. *Harvard Business Review,* 81(9): 66-75.

Clarkson, G., & Toh, P. K. 2010. 'Keep out'signs: the role of deterrence in the competition for resources. *Strategic Management Journal,* 31(11):1202-1225.

Claussen, J., Kretschmer, T., & Stieglitz, N. 2015. Vertical scope, turbulence, and the benefits of commitment and flexibility. *Management Science*, 61(4): 915-929.

CNET. 2006. Flat-screen war heats up, LCD catching up. https://www.cnet.com/news/flat-screen-war-heats-up-lcd-catching-up/. Access July 14, 2019.

Collis, D. J., & Montgomery, C. A. 2004. *Corporate strategy: Resources and the scope of the firm (2nd ed.)*. Chicago: McGraw-Hill Irwin.

Cui, A. S., & O'Connor, G. 2012. Alliance portfolio resource diversity and firm innovation. *Journal of Marketing*, 76(4): 24-43.

Cusumano, M. A., Mylonadis, Y., & Rosenbloom, R. S. 1992. Strategic maneuvering and mass-market dynamics: The triumph of VHS over Beta. *The Business History Review*, 51-94.

David, P. A. 1985. Clio and the Economics of QWERTY. *The American Economic Review*, 75(2): 332-337.

David, R. J., Sine, W. D., & Haveman, H. A. 2013. Seizing opportunity in emerging fields: How institutional entrepreneurs legitimated the professional form of management consulting. *Organization Science*, 24(2): 356-377.

Davis, G. F., Diekmann, K. A., & Tinsley, C. H. 1994. The decline and fall of the conglomerate firm in the 1980s: The deinstitutionalization of an organizational form. *American Sociological Review*, 59: 547-547.

Doblinger, C., Surana, K., & Anadon, L. D. 2019. Governments as partners: The role of alliances in US cleantech startup innovation. *Research Policy,* 48(6): 1458-1475.

Dobrev, S. D., & Gotsopoulos, A. 2010. Legitimacy vacuum, structural imprinting, and the first mover disadvantage. *Academy of Management Journal,* 53(5): 1153-1174.

Doh, J. P. 2000. Entrepreneurial privatization strategies: Order of entry and local partner collaboration as sources of competitive advantage. *Academy of Management Review*, 25(3): 551-571.

Dosi, G. 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. *Research policy*, 11(3): 147-162.

Drori, I., Honig, B., & Sheaffer, Z. 2009. The life cycle of an internet firm: Scripts, legitimacy, and identity. *Entrepreneurship Theory and Practice*, 33(3): 715-738.

Echambadi, R., Campbell, B., & Agarwal, R. 2006. Encouraging best practice in quantitative management research: An incomplete list of opportunities. *Journal of Management Studies*, 43(8): 1801-1820.

Eggers, J. P. 2012. Falling flat: Failed technologies and investment under uncertainty. *Administrative Science Quarterly*, 57(1): 47-80.

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

Ghemawat, P. 1991. *Commitment*. Simon and Schuster.

Ghemawat, P., & Del Sol, P. 1998. Commitment versus flexibility? *California Management Review,* 40(4): 26-42.

Grewal, R., & Tansuhaj, P. 2001. Building organizational capabilities for managing economic crisis: The role of market orientation and strategic flexibility. *Journal of Marketing*, 65(2): 67-80.

Greve, H. R. 2009. Bigger and safer: The diffusion of competitive advantage. *Strategic Management Journal*, 30(1): 1-23.

Greve, H. R., & Seidel, M. D. L. 2015. The thin red line between success and failure: Path dependence in the diffusion of innovative production technologies. *Strategic Management Journal*, 36(4): 475-496.

Gunther McGrath, R., & Nerkar, A. 2004. Real options reasoning and a new look at the R&D investment strategies of pharmaceutical firms. *Strategic Management Journal*, 25(1): 1-21.

Haunschild, P. R., & Sullivan, B. N. 2002. Learning from complexity: Effects of prior accidents and incidents on airlines' learning. *Administrative Science Quarterly*, 47(4): 609-643.

Hargadon, A. B., & Douglas, Y. 2001. When innovations meet institutions: Edison and the design of the electric light. *Administrative Science Quarterly*, 46(3): 476-501.

Hennart, J. F. 1993. Explaining the swollen middle: Why most transactions are a mix of "market" and "hierarchy". *Organization Science*, 4(4): 529-547.

Hu, A. 2010. Propensity to patent, competition and China's foreign patenting surge. *Research Policy*, 39(7), 985-993.

Hu, S., He, Z. L., Blettner, D. P., & Bettis, R. A. 2017. Conflict inside and outside: Social comparisons and attention shifts in multidivisional firms. *Strategic Management Journal,* 38(7): 1435-1454.

Huang, K. G., & Li, J. 2019. Adopting knowledge from reverse innovations? Transnational patents and signaling from an emerging economy. *Journal of International Business Studies*, 50(7): 1078-1102.

Huy, Q., & Vuori, T. 2015. Who Killed Nokia? Nokia Did. *INSEAD Knowledge*, September 22.

Joshi, A. M., & Nerkar, A. 2011. When do strategic alliances inhibit innovation by firms? Evidence from patent pools in the global optical disc industry. *Strategic Management Journal*, 32(11): 1139-1160.

Kacperczyk, A., Beckman, C. M., & Moliterno, T. P. 2015. Disentangling risk and change: Internal and external social comparison in the mutual fund industry. *Administrative Science Quarterly*, 60(2): 228-262.

Kacperczyk, A., & Younkin, P. 2017. The paradox of breadth: The tension between experience and legitimacy in the transition to entrepreneurship. *Administrative Science Quarterly*, 62(4): 731-764.

Kent, D., & Dacin, M. T. 2013. Bankers at the gate: Microfinance and the high cost of borrowed logics. *Journal of Business Venturing*, 28(6): 759-773.

Kerin, R. A., Varadarajan, P. R., & Peterson, R. A. 1992. First-mover advantage: A synthesis, conceptual framework, and research propositions. *Journal of Marketing*, 56(4): 33-52.

Keupp, M. M., Beckenbauer, A., & Gassmann, O. 2010. Enforcing intellectual property rights in weak appropriability regimes. *Management International Review*, 50(1): 109-130.

Keupp, M. M., Friesike, S., & Von Zedtwitz, M. 2012. How do foreign firms patent in emerging economies with weak appropriability regimes? Archetypes and motives. *Research Policy*, 41(8): 1422-1439.

Klepper, S., & Graddy, E. 1990. The evolution of new industries and the determinants of market structure. *The RAND Journal of Economics*, 27-44.

Klingebiel, R., & Rammer, C. 2014. Resource allocation strategy for innovation portfolio management. *Strategic Management Journal*, 35(2): 246-268.

Knott, A. M. 2001. The dynamic value of hierarchy. *Management Science*, 47(3): 430-448.

Knott, A. M. 2002. Exploration and exploitation as complements. In N. Bontis & C.W. Choo (Eds.), *The strategic management of intellectual capital and organizational knowledge* (pp. 339–358). New York: Oxford University Press.

Knott, A. M., & Turner, S. F. 2019. An innovation theory of headquarters value in multibusiness firms. *Organization Science*, 30(1): 19-39.

Lange, D., Boivie, S., & Henderson, A. D. 2009. The parenting paradox: How multibusiness diversifiers endorse disruptive technologies while their corporate children struggle. *Academy of Management Journal*, 52(1): 179-198.

Larkin, I. 2014. The cost of high-powered incentives: Employee gaming in enterprise software sales. *Journal of Labor Economics*, 32(2): 199-227.

Lawrence, T. B., & Suddaby, R. 2006. Institutions and institutional work. *The Sage handbook of organization studies*, 215.

Lieberman, M. B., & Montgomery, D. B. 1988. First ‐ mover advantages. *Strategic Management Journal*, 9(S1): 41-58.

Luo, Y. 2007. Are joint venture partners more opportunistic in a more volatile environment? *Strategic Management Journal*, 28(1): 39-60.

Mahmood, I. P., Zhu, H., & Zaheer, A. 2017. Centralization of intragroup equity ties and performance of business group affiliates. *Strategic Management Journal*, 38(5): 1082-1100.

March, J. G., & Simon, H. A. 1958. *Organizations*. New York.

March, J. G. 1991. Exploration and exploitation in organizational learning. *Organization Science*, 2(1): 71-87.

Mascarenhas, B. 1992. Order of entry and performance in international markets. *Strategic Management Journal*, 13(7): 499-510.

McGrath, R. G. 1997. A real options logic for initiating technology positioning investments. *Academy of management Review*, 22(4): 974-996.

McKendrick, D. G., & Carroll, G. R. 2001. On the genesis of organizational forms: Evidence from the market for disk arrays. *Organization Science*, 12(6): 661-682.

McKendrick, D. G., Jaffee, J., Carroll, G. R., & Khessina, O. M. 2003. In the bud? Disk array producers as a (possibly) emergent organizational form. *Administrative Science Quarterly*, 48(1): 60-93.

Miller, K. D., & Folta, T. B. 2002. Option value and entry timing. *Strategic Management Journal*, 23(7): 655-665.

Moeen, M. 2017. Entry into Nascent Industries: Disentangling a Firm's Capability Portfolio at the Time of Investment Versus Market Entry. *Strategic Management Journal,* 38(10): 1986-2004.

Nadkarni, S., & Narayanan, V. K. 2007. Strategic schemas, strategic flexibility, and firm performance: The moderating role of industry clockspeed. *Strategic Management Journal*, 28(3): 243-270.

Nelson, R. R., & Winter, S. G. 1982. The Schumpeterian tradeoff revisited. *The American Economic Review*, 72(1): 114-132.

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

Parente, R., Melo, M., Andrews, D., Kumaraswamy, A., & Vasconcelos, F. 2020. Public sector organizations and agricultural catch-up dilemma in emerging markets: The orchestrating role of Embrapa in Brazil. *Journal of International Business Studies*, 1-25.

Pierce, L. 2012. Organizational structure and the limits of knowledge sharing: Incentive conflict and agency in car leasing. *Management Science*, 58(6): 1106-1121.

Pisano, G. 2006. Profiting from innovation and the intellectual property revolution. *Research Policy*, 35(8): 1122-1130.

Porac, J. F., Thomas, H., Wilson, F., Paton, D., & Kanfer, A. 1995. Rivalry and the industry model of Scottish knitwear producers. *Administrative Science Quarterly,* 203-227.

Potter, A., & Wilhelm, M. M. 2019. Antecedents and Consequences of Supply Network Enabled Innovation: Evidence from Toyota. *Academy of Management Proceedings,* 1, 15447.

Raisch, S., & Birkinshaw, J. 2008. Organizational ambidexterity: Antecedents, outcomes, and moderators. *Journal of Management*, 34(3): 375-409.

Raffaelli, R. 2019. Technology reemergence: Creating new value for old technologies in Swiss mechanical watchmaking, 1970–2008. *Administrative Science Quarterly*, 64(3): 576-618.

Rindova, V. P., & Kotha, S. 2001. Continuous "morphing": Competing through dynamic capabilities, form, and function. *Academy of Management Journal*, 44(6): 1263-1280.

Rosa, J. A., Porac, J. F., Runser-Spanjol, J., & Saxon, M. S. 1999. Sociocognitive dynamics in a product market. *Journal of Marketing*, 63(4): 64-77.

Rothaermel, F. T. 2016. Competitive advantage in technology intensive industries. In *Technological innovation: Generating economic results*. Emerald Group Publishing Limited.

Ruebottom, T. 2013. The microstructures of rhetorical strategy in social entrepreneurship: Building legitimacy through heroes and villains. *Journal of Business Venturing*, 28(1): 98-116.

Rumelt, R. P. 1974. *Strategy, structure, and economic performance.* Boston: Harvard Business School, Division of Research.

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

Schilling, M. A. 2002. Technology success and failure in winner-take-all markets: The impact of learning orientation, timing, and network externalities. *Academy of Management Journal*, 45(2): 387-398.

Soda, G. 2011. The management of firms' alliance network positioning: Implications for innovation. *European Management Journal*, 29(5): 377-388.

Soh, P. H. 2010. Network patterns and competitive advantage before the emergence of a dominant design. *Strategic Management Journal*, 31(4): 438-461.

Song, J., Lee, K., & Khanna, T. 2016. Dynamic capabilities at Samsung: Optimizing internal co-opetition. *California Management Review*, 58(4): 118-140.

Suarez, F. F. 2004. Battles for technological dominance: an integrative framework. *Research Policy,* 33(2): 271-286.

Tannas, L. E. 1994. Evolution of flat-panel displays. *Proceedings of the IEEE*, 82(4): 499-509.

Teece, D.J., 1986. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy. *Research Policy*, 15, 285–305.

Toh, P. K., & Kim, T. 2013. Why put all your eggs in one basket? A competition-based view of how technological uncertainty affects a firm's technological specialization. *Organization Science*, 24(4): 1214-1236.

Tripsas, M., & Gavetti, G. 2000. Capabilities, cognition, and inertia: Evidence from digital imaging. *Strategic Management Journal*, 21(10‐11): 1147-1161.

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

Trigeorgis, L., & Reuer, J. J. 2017. Real options theory in strategic management. *Strategic Management Journal*, 38(1): 42-63.

Williamson, O. E. 1975. *Markets and hierarchies*. New York: Free Press.

Wong, P. K., & Mathews, J. A. 1998. Competing in the global flat panel display industry: introduction. *Industry and Innovation*, 5(1): 1-10.

Table 1. Technology Choice at Entry and Their Subsequent Knowledge Creation

	All firms		Late entrants					
	LCD	PDP	LCD	PDP	LCD	PDP	LCD	PDP
	Model 1a	Model 1b	Model 2a	Model 2b	Model 3a	Model 3b	Model 4a	Model 4b
Enter with both	-0.092+	0.179**	-0.001	0.310**	0.033	0.425**	0.009	0.357**
	(0.052)	(0.053)	(0.062)	(0.059)	(0.069)	(0.069)	(0.064)	(0.061)
Enter with PDP	-0.510**	0.136+	-0.542**	0.354**	-0.512**	0.400**	-0.594**	0.328**
	(0.078)	(0.079)	(0.110)	(0.100)	(0.117)	(0.108)	(0.115)	(0.103)
Enter with both * Strong business group structure					0.198+	-0.174		
					(0.110)	(0.106)		
Enter with PDP * Strong business group structure					0.174	-0.057		
					(0.251)	(0.245)		
Enter with LCD * Strong business group structure					0.326**	0.209**		
					(0.057)	(0.063)		
Enter with both * Focus on emerging markets							0.438**	0.299**
							(0.026)	(0.036)
Enter with PDP * Focus on emerging markets							0.551**	0.470**
							(0.048)	(0.044)
Enter with LCD * Focus on emerging markets							0.452**	0.428**
							(0.012)	(0.018)
Strong business group structure	0.248**	0.117*	0.301**	0.119*			0.296**	0.120*
	(0.043)	(0.049)	(0.052)	(0.057)			(0.052)	(0.057)
Focus on emerging markets	0.472**	0.410**	0.458**	0.409**	0.460**	0.410**		
	(0.011)	(0.015)	(0.011)	(0.016)	(0.011)	(0.016)		
LCD patent stock	1.057**	0.256**	0.930**	0.241**	0.933**	0.239**	0.926**	0.235**
	(0.030)	(0.036)	(0.034)	(0.039)	(0.034)	(0.039)	(0.034)	(0.039)
Plasma patent stock	0.035	1.087**	0.088*	1.153**	0.091*	1.163**	0.083+	1.153**
	(0.036)	(0.035)	(0.043)	(0.039)	(0.043)	(0.039)	(0.043)	(0.040)
General FPD patent stock	0.159**	-0.043	0.125**	-0.136**	0.123**	-0.138**	0.132**	-0.133**
	(0.033)	(0.032)	(0.040)	(0.037)	(0.040)	(0.037)	(0.040)	(0.037)
Alliance	0.039	0.147**	0.006	0.149**	0.006	0.145**	0.004	0.152**
	(0.024)	(0.036)	(0.026)	(0.042)	(0.026)	(0.042)	(0.026)	(0.042)
Focus on major FPD markets (US, Japan and Korea)	1.012**	0.909**	1.006**	0.909**	1.008**	0.913**	1.004**	0.912**
	(0.014)	(0.025)	(0.014)	(0.028)	(0.015)	(0.028)	(0.014)	(0.028)
Independent firms	-0.022	-0.130**	-0.078+	-0.157**	-0.078+	-0.162**	-0.078+	-0.155**
	(0.038)	(0.048)	(0.043)	(0.052)	(0.043)	(0.052)	(0.043)	(0.052)
Fortune global 500	0.114**	0.118**	0.114*	0.164**	0.116*	0.165**	0.118*	0.171**
	(0.042)	(0.044)	(0.051)	(0.051)	(0.050)	(0.051)	(0.051)	(0.051)
Early entrants	-0.252**	-0.470**						
	(0.053)	(0.052)						
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	15,029	14,185	11,710	11,605	11,710	11,605	11,710	11,605
Number of business groups (or independen firms)	1,166	1,166	1,037	1,037	1,037	1,037	1,037	1,037

** p<0.01, * p<0.05, + p<0.1. Standard errors in parentheses

Table 2. Late Entrants' Technology Choice at Entry

and Their Subsequent Knowledge Creation: Split-sample Analysis

	Firms entering between 1983 and 1990				Firms entering after 1990			
	LCD	PDP	LCD	PDP	LCD	PDP	LCD	PDP
	Model 5a	Model 5b	Model 6a	Model 6b	Model 7a	Model 7b	Model 8a	Model 8b
Enter with both	0.100	0.332**	0.080	0.440**	0.070	0.341**	0.125	0.443**
	(0.068)	(0.071)	(0.079)	(0.086)	(0.105)	(0.113)	(0.110)	(0.118)
Enter with PDP	-0.385**	0.211+	-0.317*	0.279*	-0.211	0.899**	-0.410+	0.964**
	(0.123)	(0.123)	(0.130)	(0.131)	(0.183)	(0.168)	(0.209)	(0.186)
Enter with both * Strong business group structure			0.249*	-0.138			-0.103	-0.836**
			(0.117)	(0.120)			(0.292)	(0.320)
Enter with PDP * Strong business group structure			-0.342	-0.315			1.193**	-0.158
			(0.325)	(0.337)			(0.426)	(0.378)
Enter with LCD * Strong business group structure			0.187**	0.157*			0.452**	0.214*
			(0.070)	(0.079)			(0.093)	(0.105)
Focus on emerging markets	0.620**	0.515**	0.620**	0.517**	0.422**	0.343**	0.421**	0.353**
	(0.024)	(0.036)	(0.024)	(0.036)	(0.014)	(0.019)	(0.014)	(0.019)
LCD patent stock	1.081**	0.215**	1.077**	0.213**	1.206**	0.428**	1.203**	0.423**
	(0.045)	(0.053)	(0.045)	(0.053)	(0.052)	(0.064)	(0.052)	(0.064)
Plasma patent stock	0.112*	1.140**	0.110*	1.152**	-0.041	1.214**	-0.059	1.210**
	(0.052)	(0.051)	(0.052)	(0.051)	(0.064)	(0.061)	(0.065)	(0.062)
General FPD patent stock	0.127**	-0.048	0.127**	-0.056	0.187**	-0.231**	0.199**	-0.228**
	(0.047)	(0.045)	(0.047)	(0.045)	(0.066)	(0.066)	(0.066)	(0.066)
Alliance	-0.001	0.084	0.001	0.081	0.089+	0.197**	0.079	0.194**
	(0.037)	(0.053)	(0.037)	(0.053)	(0.050)	(0.072)	(0.049)	(0.072)
Focus on major FPD markets (US, Japan and Korea)	1.100**	0.942**	1.100**	0.944**	1.036**	0.906**	1.037**	0.911**
	(0.023)	(0.039)	(0.023)	(0.040)	(0.024)	(0.042)	(0.024)	(0.042)
Independent firms	-0.143**	-0.340**	-0.144**	-0.350**	-0.080	0.009	-0.071	0.006
	(0.055)	(0.068)	(0.055)	(0.069)	(0.065)	(0.081)	(0.065)	(0.081)
Fortune global 500	0.208**	0.238**	0.209**	0.239**	0.095	0.094	0.123	0.101
	(0.055)	(0.062)	(0.056)	(0.062)	(0.086)	(0.095)	(0.086)	(0.095)
Strong business group structure	0.184**	0.068			0.432**	0.128		
	(0.062)	(0.070)			(0.088)	(0.100)		
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,731	6,626	6,731	6,626	4,979	4,979	4,979	4,979
Number of aeid	382	382	382	382	655	655	655	655

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

Figure 1. Emergence of LCD and PDP Technology

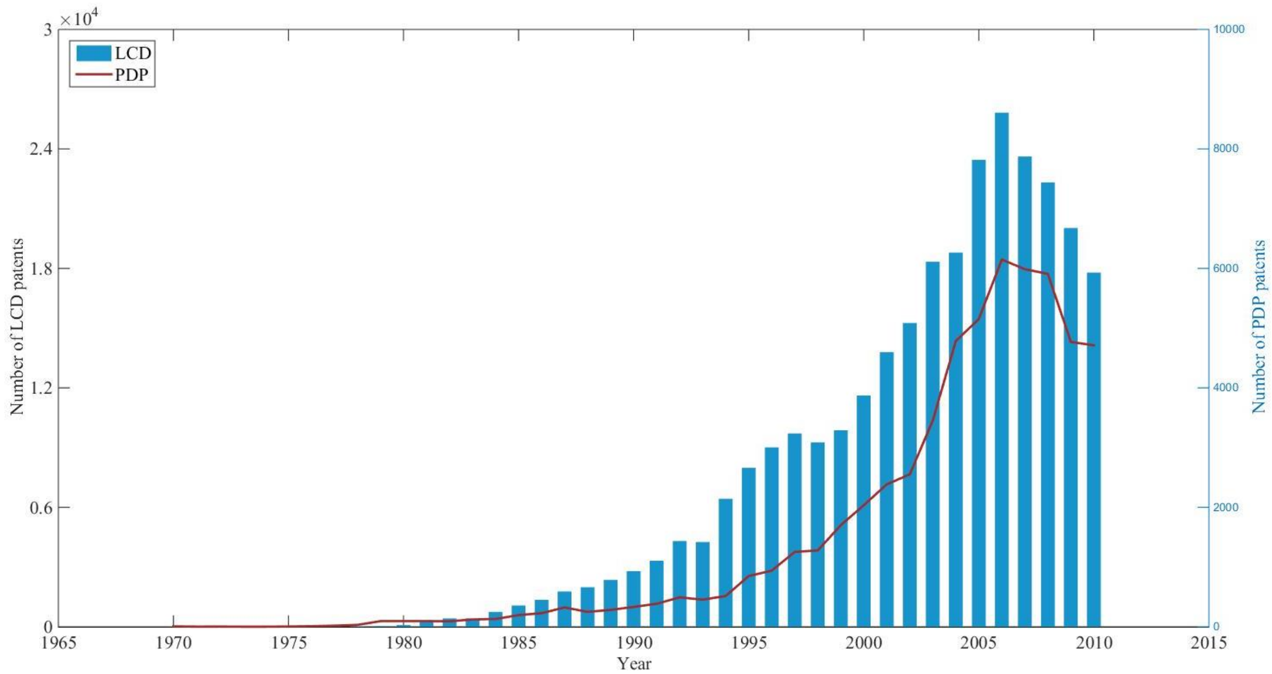
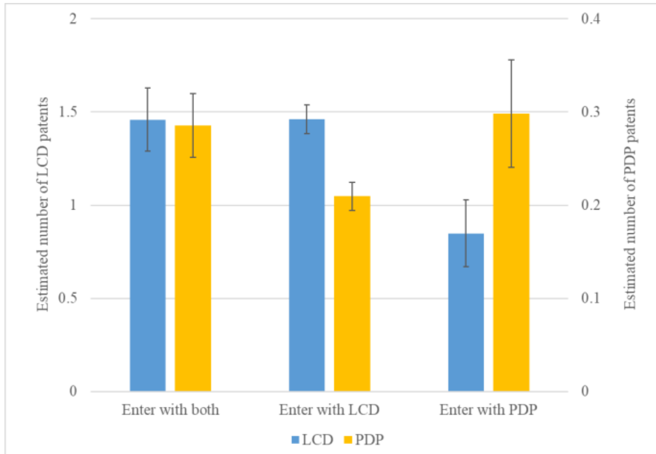


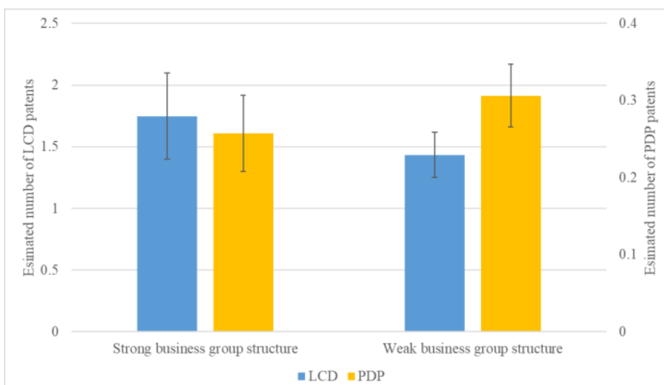
Figure 2. Firms' Technology Choice at Entry by Entry Year

Figure 3. Estimated Number of LCD and PDP Patents

Panel A. Estimated number of patents for late entrants with different technology choices at entry



Panel B. Estimated number of patents for firms with different organizational structure
(among late entrants entering with both LCD and PDP)



Panel C. Estimated number of patents with different geographical foci
(among late entrants entering with both LCD and PDP)