# LAGGARD STRATEGY: WHY A FIRM IS SOMETIMES BETTER OFF LAGGING THE TECHNOLOGY FRONTIER


BY

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DISSERTATION

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## ABSTRACT

This dissertation focuses on using organizational capabilities and the anticipated economic payoff from innovation to explain and predict the dynamics of a technological laggard's behavior. The firm capabilities research that focuses on organizational capabilities suggests that a technological laggard has to innovate, while the competitive dynamics research focuses on the anticipated economic payoff that a technological laggard can gain from innovating. Together, the central hypothesis in this dissertation is that a firm is more likely to remain a technological laggard if doing so enables the firm to better utilize its current organizational capabilities, and if it anticipates a better economic payoff by remaining a technological laggard than by becoming a technological leader in innovation. A technological laggard chooses to move to the technology frontier when it has the capabilities to realize the anticipated economic payoff. Using panel data from the flat panel display industry for the 1991-2008 period, I empirically corroborate the hypothesis. This dissertation provides a more complete picture than the extant literature of a technological laggard's behavior by combining the firm capabilities research with competitive dynamics research.

*To Mother and Father*

## ACKNOWLEDGEMENTS

There are so many people I would like to thank. Hence, comprehensively, I thank God.

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# CHAPTER 1

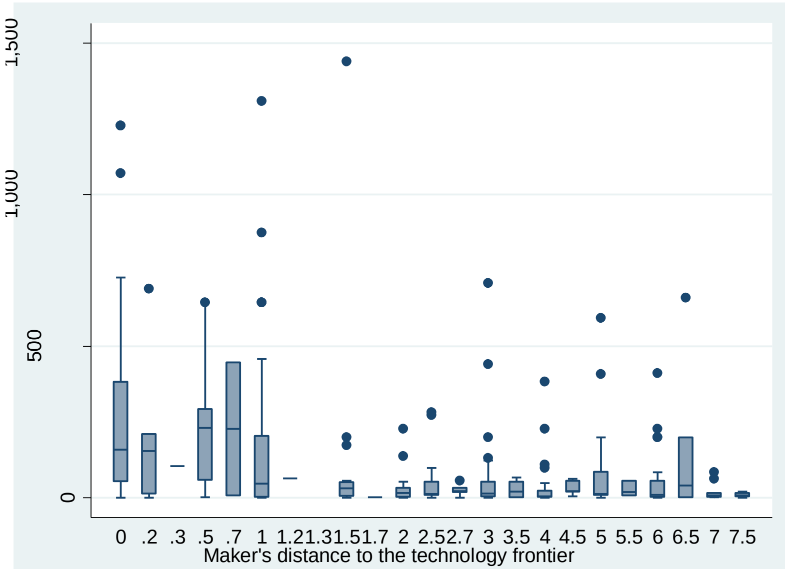
# INTRODUCTION

The large volume of research on competition at the technology frontier[1] (Banbury & Mitchell, 1995; Jovanovic & Macdonald, 1994; Reinganum, 1983) belies a simple empirical reality--at any point of time, most firms lag behind their industry's technology frontier. Indeed, few if any firms are consistently at the technology frontier and many firms spend the most of their existence behind the technology frontier. Despite this ubiquity, we understand little about the strategies of technological laggards (Grenadier & Weiss, 1997). This dissertation focuses on one critical decision technological laggards must make--whether to attempt to advance to a new position, and if so, whether to move partway towards the technology frontier, or whether to move all the way to the technology frontier[2].

[1] de Figueiredo & Teece define the technological frontier as "a component or service being procured which enlists technology that is not ubiquitously employed in the industry. Frontier technologies are those leading edge innovations being incorporated into subsystems and components" (1996: 545, footnote 5). Thus, the technology frontier in this study represents the most advanced technology available in the market (Agarwal, Echambadi, Franco & Sarkar, 2004; Christensen, 1997; de Figueiredo & Kyle, 2005).

[2] In this dissertation I examine the technology advancements within the same technology trajectory (Dosi, 1982). The setting facilitating incremental technology advancement where a technological laggard to have three proposed strategic alternatives: (1) not move; (2) move towards; and (3) move to the technology frontier.

**Figure 1. Patent counts by distance to the technology frontier.**




Note: Box's upper hinge represents $75_{th}$ percentile; lower hinges represents $25_{th}$ percentile. Maker's distance is the generation difference between the industry's most advanced plant generation and its most advanced plant generation

Not all firms are equally capable of competing effectively at the technology frontier. Specifically, some firms may have difficulty developing their technological capabilities in such a timely manner that allows them to move to the technology frontier (Helfat & Peteraf, 2003). Figure 1 illustrates flat panel makers' distance to the technology frontier with respect to their patent numbers, which are common proxies of firms' technological capabilities (Hall, Jaffe & Trajtenberg, 2001; Jaffe & Trajtenberg, 2002). Some flat-panel display makers behind the technology frontier actually have more patents than those close to or at the technology frontier, suggesting that makers can and may strategically select a position in relation to the technology frontier (Khanna, 1995; Lerner, 1997). Indeed, Chen, Smith and Grimm have called for future studies that "explore the characteristics of the firms which initiate actions and the process by which competitors decide to respond," (1992:453). In additional to technological capabilities, a model that explains and predicts a firm's innovation behavior should include factors influencing its likelihood of taking and responding competitive actions.

**1.1 Research Question**

In an attempt to respond to the issues raised above, this dissertation asks the central research question: *What determines by how much, if at all, a technological laggard advances towards the technology frontier?* I integrate the firm capabilities and competitive dynamics researches into a theoretical model in an effort to better understand the technology deployment decisions made by technological laggards (Cui, Calantone & Griffith, 2011; Ndofor, Sirmon & He, 2011). This integrated model seeks to address the theoretical gaps in each underlying literature. The firm capabilities research adopts an inward-looking focus, considering the focal firm's capabilities (Conner & Prahalad, 1996; Mayer & Argyres, 2004; Mitchell & Shaver, 2003); while in contrast the competitive dynamics research which considers the focal firm's capabilities of giving and responding to competitive actions from the environment[3]. The development of competitive dynamics research has largely focused on a firm's level of competition awareness, and the resulting motivation to take competitive actions (Chen, 1996), leaving the effect of organizational capabilities on the focal firm’s competitive behavior largely unexamined. It is of theoretical importance to examinate the focal firm's organizational capabilities in a competitive environment. Because of the strategic interdependencies between the focal and rival firms, the strength of the focal firm's organizational capabilities is likely to for the most part be correlated with those of its rival firms'.

The firm capabilities research posits that a technological laggard chooses a strategic move that can increases and enhance the utility of its existing organizational capabilities. Therefore, a technological laggard is likely to not move from its current position if remaining in the current position allows it to better utilize its organization capabilities. This proposition

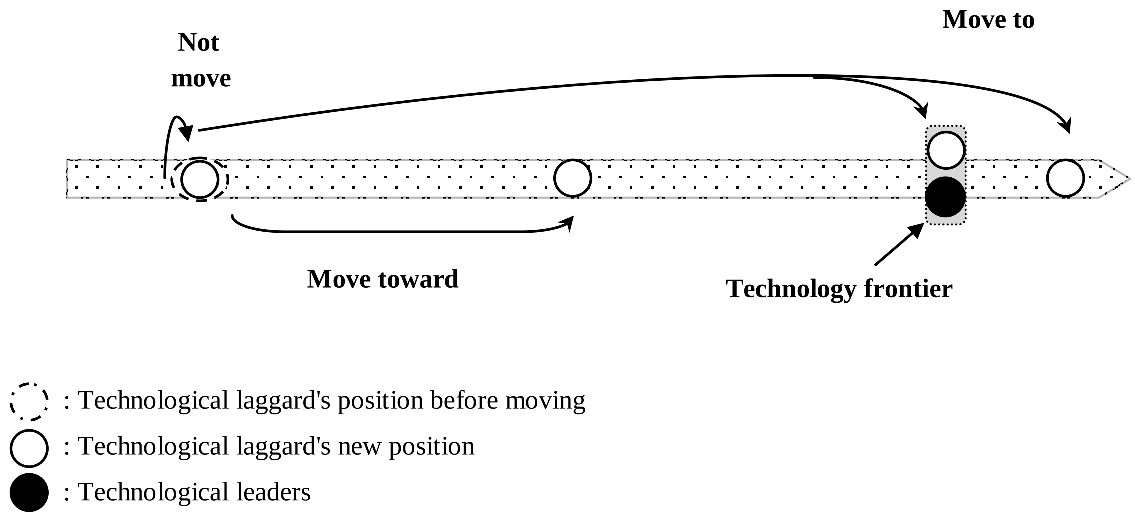
[3] The external factors in this dissertation specifically refer to market and technological competition from rivalry.

challenges the assumption widely held in the competitive dynamics research, which posits that an increasing level of competition induces a technological laggard to take actions, assuming that managers respond to the competition by initiating changes (Cyert & March, 1963; Greve, 2011; Levinthal & March, 1993). But this assumption overlooks the fact that not moving can also be a strategic decision that enables a technological laggard to leverage its existing organizational capabilities, as suggested by the firm capabilities research.

Through a model that combines the firm capabilities and the competitive dynamics research, I posit that a technological laggard's technology deployment decisions are contingent both on its organizational capabilities and its anticipated economic payoff. However, if a technological laggard is less than capable of managing the risks involved in moving to the technology frontier, it usually chooses not to move from its current position, or move towards the technology frontier. Being behind the technology frontier can sometimes enable a technological laggard to garner a significant economic payoff from time to time.

The model in this dissertation is particularly useful in terms of explaining and predicting technology deployment decisions made by technological laggards. Technological laggards are made up of a group that is highly heterogeneous in their organizational capabilities; this group as a whole has exhibited a more diverse pattern of competition than has the technological leader (Pacheco-de-Almeida & Zemsky, 2012). Thus, to fully understand a technological laggard's technology deployment decision, it is necessary to include the heterogeneity that is also inherent in competitive actions that a technological laggard takes in addition to the heterogeneity in capabilities (Chatain, 2010; Lee, Kim & Lim, 2011).

**Figure 2. The three strategic alternatives of a technological laggard.**




Despite the fact that technological laggards do innovate, the extant research literature rarely addresses innovation that mostly occurs behind the technology frontier. Figure 2 illustrates three strategic alternatives that are available to a technological laggard in the current dissertation with respect to its distance to the technology frontier: (1) to *not move* from its current position; (2) to *move towards* the technology frontier; (3) to *move to* the technology frontier[4].

## 1.2 Industry Setting and Research Design

I begin this dissertation by posing the research question: "What determines by how much, if at all, a technological laggard advances towards the technology frontier?" I use data from the worldwide flat panel display industry for the following four reasons. First, the size of glass substrate, which is later divided into display panels, is a single dimension that can be used to defines a plant's generation in this industry, and thus will allow for a much greater precision in

[4] Moving to the technology frontier in this study represents two strategic actions--*moving to* and *beyond* the technology frontier. Although in practice the two moves are different, the extant theories cannot distinguish the two in developing hypotheses. Therefore, I combine these two moves and refer them as *moving to* the technology frontier.

empirical testing. Second, it is widely accepted that plant generation is a measure of a firm's technological capabilities in the flat panel display industry, and the introduction of this measure can be viewed as a contribution to the extant research literature. Third, an across-the-board comparison of each firm' plant generations provides a clear identification as to who the technological leader and laggards are, and the distance between them, as measured in the generations of plants, lends itself as an empirical setting to examine the behavior of technological laggards. Fourth, the product characteristics of display panels are nearly identical across the entire flat panel display industry. Due to the gradual and quite uniform transformations of products from inputs into outputs, there is high face validity in classifying technological laggards of the same plant generation into the same category (Vives, 2005). This consistent connection between inputs and outputs once again enhances the precision of the empirical testing.

### 1.3 Contributions

Technological capabilities alone may be insufficient to ensure a firm's performance, but a firm's capabilities to manage the competitive dynamics in its market can help it to improve its performance (Tsai, Su & Chen, 2011; Sirmon, Hitt & Ireland, 2007). This dissertation contributes to the extant literature by proposing a model which combines the firm capabilities and competitive dynamics researches. Chen's (1996) Awareness-Motivation-Capability model underscores the importance of the focal and rival firm's organizational capabilities in facilitating competitive actions. Although awareness and motivation usually induce a firm to plan competitive actions, it also needs to have corresponding capabilities to actually implement intended competitive actions. The current dissertation on a technological laggard's behavior with respect to its decision to *move towards* or *to* the technology frontier not only further builds on

Chen's (1996) model in a technological context, but also highlights the importance of organizational capabilities in carrying out a firm’s competitive actions. Furthermore, the model in the current study incorporates a technological laggard's anticipated economic payoff from innovation as another factor to address the motivation issues raised in Chen's (1996) model. Examples from the flat panel display industry suggest that some firms may strategically choose to be technological laggards because being lagging allows them to achieve a higher profitability than from being the technological leader. Also, there still remains a theoretical tension in the competitive dynamics research regarding the degree to which firms should innovate in a competitive market (Aghion *et al.*, 2005; Dutta, Lach & Rustichini, 1995; Graevenitz, 2005). The current study seeks to reconcile this particular issue by examining a technological laggard’s capabilities to protect its anticipated economic payoff in a competitive market, which subsequently determines to what extent a technological laggard chooses to innovate. Finally, the specific focus on technological laggards enables the current study to provide a relevant context in which it can supply managerial implications that are meaningful to many practitioners, because few managers are at the “winning” firms.

## CHAPTER 2

## REVIEW OF THE RESEARCH LITERATURE

**Figure 3. Theory overview.**

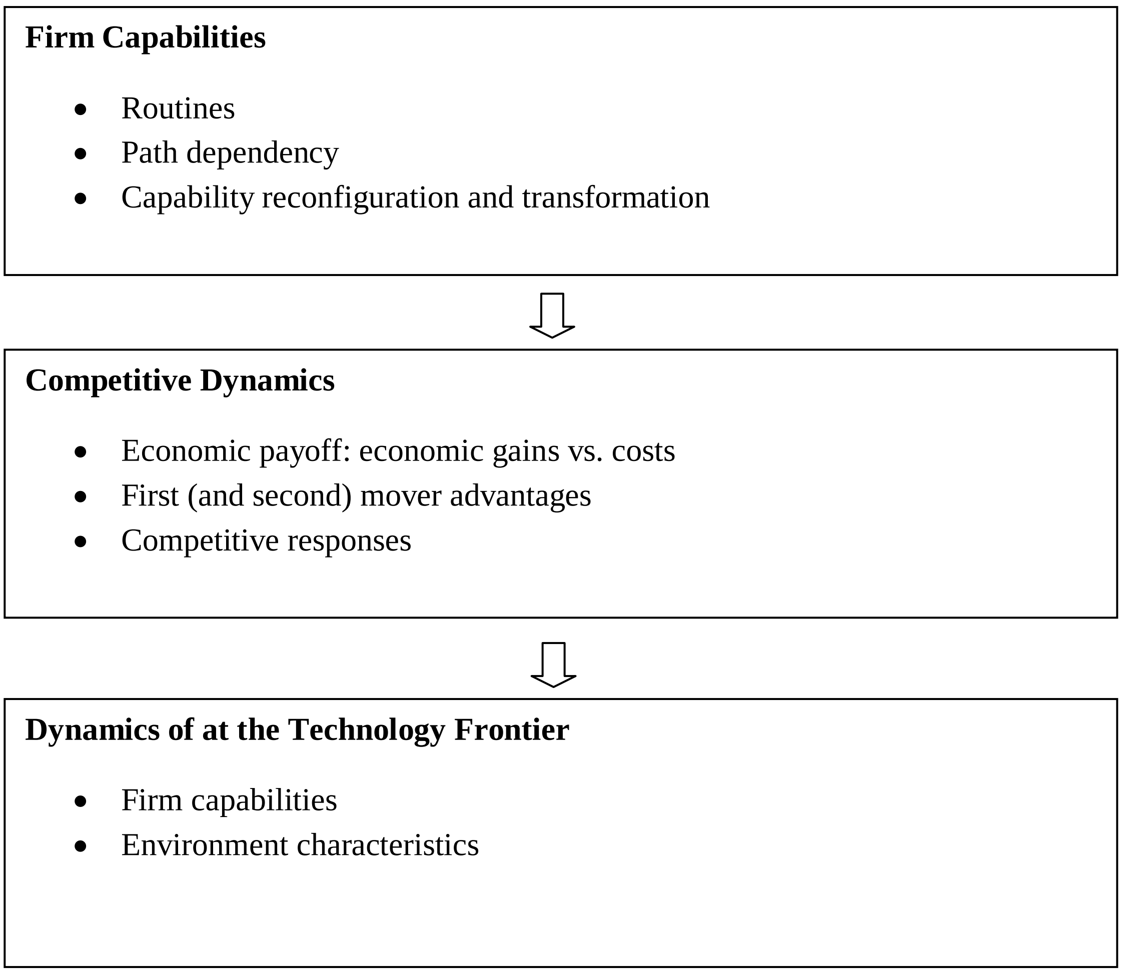



Figure 3 presents the available and most pertinent theories that can help to explain a technological laggard's strategic moves, and illustrates the theory construction in this dissertation.

## 2.1 Firm Capabilities

Firm capabilities research provides a disciplinary foundation for examining organizational capabilities, technology competition, and the dynamics at the technology frontier. Helfat and Peteraf define organizational capabilities as: "the ability of an organization to perform a coordinated set of tasks, utilizing organization resources, for the purpose of achieving a particular end result" (2003: 999). For example, organizational capabilities can enable a technological laggard to better leverage both economies of scale and scope (Chandler, 1990). This dissertation focuses on an important complementary end result to Chandler's work (1990) concerning whether a technological laggard moves *towards,* or *to* the technology frontier. One of the reasons as to why we have observed a variety of strategic moves is because technological laggards' resources and capabilities are generally more heterogeneous (Peteraf, 1993).

*Routines & path dependency*

In order to remain viable as an industry player, a technological laggard often continually develops new capabilities, which usually build upon their current capabilities (Mitchell & Shaver, 2003). Indeed, a technological laggard typically develops its capabilities in a path-dependent process that is based upon an organization's own specific routines (Conner & Prahalad, 1996; Grant, 1996; Mayer & Argyres, 2004; Nelson & Winter, 1982). Because of the specificity of these routines, each technological laggard may follow a distinct path in developing its own capabilities (Itami & Roehl, 1987). Taking into account a variety of elements that may influence its dynamic environment, a technological laggard might decide to focus on investments that afford it an opportunity to explore new capabilities that stretch beyond its existing portfolio, while another laggard may choose to focus on investments that exploit its current capabilities

(Ethiraj *et al.*, 2005; Helfat, 1997; Jacobides, Knudsen & Augier, 2006; March, 1991; Santos & Eisenhardt, 2006).

*Capabilities reconfiguration and transformation*

A dynamic environment often creates challenges in which a technological laggard must develop new organizational capabilities in order to stay viable as a player in the competitive landscape. When a technological laggard attempts to utilize its current capabilities, following the existing path may nevertheless limit its options, since it may forgo the option of developing new capabilities that allow the laggard to better cope with its dynamic environment later down the road (Capron & Mitchell, 2004). The routines involved in utilizing existing capabilities can give rise to path dependency (Argyres, 1996) that sometimes lead to inertia, which is likely to effectively put a constrain on a technological laggard abilities to further developing its capabilities (Conner & Prahalad, 1996; Grindley & Teece, 1997). Part of this inertia is because when a technological laggard deviates from its current path it often runs a greater risk of failure (Tripsas, 2009). Thus, the often observed high level of difficulty that a technological laggard experiences when it attempts to develop new organizational capabilities to try and adapt to environmental changes underscores the importance of developing dynamic capabilities, which is "the firm’s ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" (Teece, Pisano & Shuen, 1997: 516). A technological laggard with superior dynamic capabilities typically is more capable of breaking away from its current path of capabilities development, if necessary. These dynamic capabilities are especially important during high volatile environments (Eisenhardt & Martin, 2000; Spanos & Prastacos, 2004; Wang & Ahmed, 2007).

The use of dynamic capabilities renders strategic renewal a possibility that later leads to a new path of capabilities development for technological laggards (Teece, 2007; Wang & Ahmed, 2007). In this process of strategic renewal, a technological laggard can integrate newly acquired knowledge from implementing strategic actions into future developments (Argyres & Liebeskind, 1999; Argyres & Zenger, 2007; Danneels, 2002; Rothaermel & Hess, 2007; Zollo & Winter, 2002). Furthermore, a technological laggard with a better absorptive capacity can generally more effectively transform such knowledge into organizational capabilities (Cohen & Levinthal, 1990; Narasimhan, Rajiv & Dutta, 2006). While recognizing the importance of renewing organizational capabilities at a time of rapid change (Helfat & Raubitschek, 2000; Winter, 2000), a technological laggard with renewed organizational capabilities still runs the risk of failure from technology competition (Peteraf, 1993), which we discuss to next.

**2.2 Competitive Dynamics**

A technological laggard has three strategic alternatives --- *not moving* from its current position, moving *towards*, and *moving to* the technology frontier (Grenadier & Weiss, 1997) in its attempt to survive (or even thrive) the often intense technology competition. The high interest in examining the economic gains and costs of alternative moves has sparked a stream of studies. For example, some have suggested a inclination to avoid direct competition with the technological leader as one of the reasons for a laggard's moving towards the technology frontier (Hawley, 1950), and seeking a less crowded position where resources are more abundant can be another (Greve, 1998a, 1998b; Schmalensee, 1978). However, a technological laggard, by definition, cannot have first mover advantages simply by moving *towards* the technology frontier. The potential for better economic gains as a first mover can encourage a technological laggard to take greater risks by attempting to move to the technology frontier. But such an attempt essentially requires a technological laggard to commercialize innovation that typically results in substantial cannibalization on products utilizing earlier innovations (Aboulnasr *et al.*, 2008; Conner, 1986; Ghemawat, 1991; Greenstein, Wade & Greenstein, 1998; Levinthal & Purohit, 1989; Norton & Bass, 1987; Reinganum, 1983). In sum, a technological laggard's decision to choose a specific strategic move is typically dependent on the anticipated economic payoff. We discuss these economic gains and costs next.

*Economic payoff: economic gains vs. costs*

Deephouse (1999) underscores the importance for a technological laggard to maintain economic gains when participating in technology competition. Initially, technology competition of moderate intensity may increase a technological laggard's incentives to innovate (Aghion *et al.*, 2005; Encaoua & Ulph, 2004). When technology competition is moderate, it is relatively easier for a technological laggard to innovate so as to surpass some of its rivals; while the technological leader continues innovating to maintain its technological leadership (Dasgupta & Stiglitz, 1980). Once technology competition becomes more intense, the technological leader and its rivals are likely to be locked in a technology race toward the commercialization of the latest innovation (Dutta, Lach & Rustichini, 1995; Fudenberg & Tirole, 1985). Intensified technology competition usually reduces a technological laggard's anticipated economic gains from innovation (Greenhalgh & Rogers, 2006), while the intensity of technology competition rarely decrease the costs of innovation (Pacheco-de-Almeida, 2010). Therefore, intensified technology competition may be especially discouraging for technological laggards who attempt to move to the technology frontier, because of low anticipated gains and high innovation costs.

There are a number of advantages being a technological laggard. First, due to prohibitively high innovation costs (Huisman & Kort, 2002), a technological laggard may be financially better off not trying to move to the technology frontier if other strategic alternatives that require lower R&D investments and/or yield a higher economic payoff become available. For instance, Eggers's (2009) empirical study of the flat panel display industry shows that technological laggards who are late in commercializing its innovation tend to have better economic performances.[5]

Second, knowledge spillovers from the technological leader may enable a technological laggard to commercialize the same or similar innovation in a more cost-effective fashion (Eeckhout & Jovanovic, 2002; Kafouros & Buckley, 2008; McGahan & Silverman, 2006). Knowledge spillovers can reduce a technological laggard's effort in developing the same or similar knowledge, thereby lowering its innovation costs and improving its economic payoff.

Third, if a technological laggard remains behind the technology frontier, it can usually continue to appropriate its innovation value for a longer time period even when technological leadership changes hands. The longer it appropriates its innovation value, the more the economic gains it is able to accumulate. If a technological laggard decides to become the technological leader, rapid technology change often leads to a short-lived position of technological leadership, and it usually has less time to appropriate its innovation value as a result (Beath, Katsoulacos & Ulph, 1987; Eggers, 2009). As such, Grenadier and Weiss (1997) suggest that the adoption of the laggard strategy at the time of rapid technology change enables a technological laggard to have a better economic payoff.

In sum, a technological laggard can have innovation costs advantage over the technological leader. Hence, the extant research suggests a possibility that a firm which seeks to maximize its economic value chooses to be a technological laggard, i.e., by having an explicit strategy of commercializing its innovation during a relatively later stage (Aghion, Harris &

[5] Unlike a technological laggard, the technological leader generally needs to innovate consistently and to be ready to commercialize the cutting-edge innovation and maintain its technological leadership (Adner & Kapoor, 2010; Hellwig & Irmen, 2001).

Vickers, 1997; Cho, Kim & Rhee, 1998; Filippini, 1999; Lilien & Yoon, 1990; Sudharshan, Liu & Ratchford, 2006). This discussion suggests that in order to determine a technological laggard's value-maximizing strategy, we must fully analyze first and second mover advantages, which we cover next.

*First (and second) mover advantages*

Glazer (1985) asks whether the first mover in an economically attractive market possesses some advantages over later entrants. A technological laggard moving beyond the current technological frontier is more likely to receive higher economic returns, if there is no competitive response from other market participants. Further, even if there are other firms entering the market later, the technological laggard that has already moved beyond the technology frontier may still stand to receive higher economic returns and/or greater market share (Banbury & Mitchell, 1995; Carow, Heron & Saxton, 2004; Dos Santos & Peffers, 1995; Huff & Robinson, 1994; Jovanovic & Macdonald, 1994; Reinganum, 1983). Thus, first mover advantages often attract a technological laggard that seeks to become the technological leader[6] (Lieberman & Montgomery, 1988; Makadok, 1998). This first-moving technological laggard who has moved beyond the technology frontier often attempts to influence the timing of product replacement, for example, to delay the commercialization of the next round of innovation (Conner, 1986; Fudenberg & Tirole, 1985; Gilbert & Newbery, 1982; Grenadier & Weiss, 1997; Hendricks, 1992; Reinganum, 1983; Sudharshan *et al.*, 2006). Furthermore, by the time rival firms begin to commercialize the newer innovation, the technological leader (i.e., the previous first-mover technological laggard) is already in a position where it can quickly commercialize the same innovation by free-riding on its rivals' experience, and to continue driving the market

[6] The first mover here is not confined to the first firm commercializing the innovation. The 'first mover' here refers to early movers. By the same token, the 'second mover' does not specifically apply to the second firm after the first firm. The 'second mover' here refers to 'late movers'.

demand for the newer innovation (Jensen, 2003; Quirmbach, 1986). In sum, the economic gains associated with being a first-moving laggard can be high (Macieira, 2006; Mitchell, 1991), even when it requires high innovation costs. C*eteris paribus,* high economic gain often associates with high costs, which motivate a technological laggard to maintain a lagging strategy to have second mover advantages.

Second mover advantages provide at least two strategic reasons as to why a technological laggard chooses to remain behind the technology frontier. First, the patterns of competition among firms at the technology frontier, which then serve as a template for following rivals which attempt to deploy more advanced technologies (Cyert & March, 1963; Haunschild & Miner, 1997; Hoetker & Agarwal, 2007; Semadeni & Anderson, 2010). Second, knowledge spillovers from the technological leader can enable a technological laggard to quickly advance down the learning curve (Eeckhout & Jovanovic, 2002; Jovanovic & MacDonald, 1994; Zhang *et al.*, 2008). Thus, a technological laggard is often able to commercialize the same innovation at lower costs than the technological leader (Bayus, Jain & Rao, 1997; de Figueiredo & Kyle, 2006; Huisman & Kort, 2002; Leiblein & Ziedonis, 2007; Markides & Geroski, 2005). In sum, substantial second mover advantages can motivate a technological laggard to strategically lag behind the technology frontier.

The extant research literature suggests that the intensity of technology competition and the temporal order of innovation commercialization both have influence over a technological laggard's strategic move. Such an analysis is more complete if the effect of the distance between the technological leader and laggard is also included.

A technological laggard typically chooses a strategic move to avoid direct competition from the technological leader. The competition is likely to be more intense when the technological leader and laggard are close in terms of their technological capabilities. Indeed, a technological laggard is likely to innovate more in order to be in a better position to move towards the technology frontier (Aghion *et al*., 2001, 2005; Alder, 2010; Boone, 2001; Macieira, 2006), or to the technology frontier (Ali, 1994; Vickers, 1986). The strategic move by the initiating firm typically lead to competitive responses from rivals, and we examine these competitive responses next.

*Competitive Responses*

A rival (i.e., the technological leader or a technological laggard) that has become aware of a particular technological laggard's initial move to the technology frontier typically reacts with its own competitive responses (Robertson, Eliashberg & Rymon, 1995). Chen's (1996) *Awareness-Motivation-Capability* framework explains when rivals are more likely to make competitive responses. As a baseline, a competitive response by some rivals[7] often increases their economic gains, not only in the short-term but because it also helps to strengthen their reputation as a strong defender (Chen *et al.*, 1992; Clark & Montgomery, 1998; Debruyne *et al*., 2002). First, rivals are more likely to react to a technological laggard's visible (tangible) moves, because they are more likely to be *aware* of the threats it poses (Chen & Hambrick, 1995; Chen *et al.*, 1992; Miller & Chen, 1994a; 1994b). Second, rivals are more *motivated* to respond and try to defend their resources and/or market share when there is a high degree of resource interdependency between a technological laggard and its rivals due to resource sharing, or when they operate in a highly concentrated market (Arend, 1999; Bain, 1951; Chen & MacMillan, 1992; Chen, 1996; Derfus, Maggitti & Smith, 2008). Third, the rivals are more likely to respond to the technological laggards initiating the move to the technology frontier because these rivals

[7] Rivals are the former technological leader and technological laggards previously deploy the most advanced technology.

are typically more *capable* of responding (Chen, Su & Tsai, 2007). In sum, rivals are more likely to make competitive responses when they become aware of the initial moves by a challenger for technology leadership, and when they are motivated and capable of carrying on competitive responses (Chen, 1996).

## 2.3 Dynamics at the Technology Frontier

*Firm capabilities*

On the one hand, a technological laggard is more likely to move to the technology frontier when it is closely behind the technological leader and therefore has less distance to the technology frontier compared with other laggards (Ali, 1994; Henderson, 1993; Huisman & Kort, 2002; Lerner, 1997; Vickers, 1986). Thus, this technological laggard often chooses to invest heavily in R&D in an attempt to move to the technology frontier (Aoki, 1991; Gilbert & Newbery, 1982; Harris & Vickers, 1985; Jovanovic & MacDonald, 1994; Schilling, 2003; Vickers, 1986). On the other hand, a technological laggard may decide not to move to the technology frontier when it is already very close to the technology frontier, because the economic payoff may not be enough to justify the R&D costs involved in implementing the move (Aghion *et al.*, 1997; Aoki, 1991; Encaoua & Ulph, 2004; Horner, 2003).

In addition to moving to the technology frontier, another issue to be considered is which firms will innovate to improve their current technological position (even if the technological laggard does not move to the technology frontier). From this perspective, Abramovitz (1986) and Khanna (1995) suggest that a technological laggard who is still far behind the technology frontier may choose to innovate more in order to narrow its distance to the technology frontier.

Moreover, strategic moves that bring a technological laggard closer to the technology frontier also causes the problem of product cannibalization (Adner & Kapoor, 2010) where the newer innovation attracts demand away from the older technology (Raybaudi, Sola & Naindebam, 2010; Tirole, 1988). Norton and Bass (1987) utilize Pearl's law[8] to illustrate that sales of newer innovation can predictably replace sales of the older technology over time (Grenadier & Weiss, 1997). Thus a technological laggard might even have a negative return on innovation due to product cannibalization (Leiblein & Ziedonis, 2007; Wörter, Rammer & Arvanitis, 2010). The greater the market share a technological laggard has, the greater the likelihood its sales are potentially cannibalized. Thus, a technological laggard with a large market share has lower economic incentives to innovate (Dutta *et al*., 1995; Ghemawat, 1991; Reinganum, 1989). Furthermore, the competitive dynamics literature suggests that a technological laggard with a large market share is less likely to respond to competitive actions (Debruyne *et al*., 2002) since maintaining its market share already consumes most of its resources. Therefore, these technological laggards are less capable of reacting to the rivalry in a timely manner (Barnett & McKendrick, 2004; Chen *et al*., 1992). Subsequently, these technological laggards are more likely to experience greater market share erosion because they often fail to react quickly enough to competitive actions (Chen *et al*., 1992; Ferrier, Smith & Grimm, 1999; Grimm & Smith, 1997; Hannan & Freeman, 1977; Lieberman & Montgomery, 1988).

In addition to considering the effect of revenue on the competitive dynamics, we also need to consider the costs associated with competitive responses. A technological laggard is less likely to receive competitive responses when rivals anticipate low the economic payoff from such a move (Aghion *et al*., 2001; Chen *et al*., 1992; Chen & Miller, 1994; Clark & Montgomery, 1998). Competitive responses from rivals are expected to be less likely when technological

[8]Pearl's law: $\ln\left(\frac{s}{1-s}\right) = kt$, where *s* is the sales of innovative product, *t* is time, and *k* is a constant.

change is rapid, in which case short-lived technological advances usually translate into lower economic gains (Kafouros & Buckley, 2008; Kafouros & Wang, 2008).

A technological laggard's economic gains depend not only on rivals' competitive responses, but also on its organizational capabilities. The more time and experiences a technological laggard has had in the relevant technological environment, the more likely it is that a technological laggard has developed organizational capabilities that can enhance its performance in the environment (Adner & Kapoor, 2010; Ferrier, 2001; Linden, Hart & Lenway, 1997). The co-evolution of a technological laggard's organizational capabilities and its technological environment might limit its choice of strategic alternatives (Hutzschenreuter & Israel, 2009; Huergo & Moreno, 2010; Jovanovic & Nyarko, 1996; Leiblein & Madsen, 2009; Lamburg *et al*., 2009; Lieberman & Montgomery, 1988; Zajac, Kraatz & Bresser, 2000). We consider the technological environment and some of its notable environmental characteristics next.

*Environmental characteristics*

A technological laggard's economic incentives to initiate competitive actions are likely to increase with the number of rivals sharing similar resources. Upon noticing competitive actions by other rivals, a technological laggard can either response in kind or does not take an action (Robertson *et al*., 1995). Because competitive actions are likely to lead to competitive responses, which can trigger a series of creative destruction (Dutta *et al*., 1995; McKelvey & Palfrey, 1991; Schumpeter, 1934), taking no action may be an overall better strategy for a technological laggard. Competitive responses are likely to lead to a more competitive environment in which a technological laggard more often than not has to settle for a lower economic payoff (Astley & Fombrun, 1983; Khandwalla, 1987; Stigler, 1964), which eventually discourages a technological laggard from innovating (Kafouros & Buckley, 2008; McGahan & Silverman, 2006). Thus, a technological laggard can strategically react to rivalry by taking no actions.

A technological laggard sharing similar resources with its rivals typically experiences stronger competitive tension (Alder, 2010; Chen *et al.*, 2007; Porac *et al*., 1995), which result in more competitive actions or attacks of a greater magnitude (Chen *et al*., 2007; Shankar, 2006). Intense technology competition due to resource similarity is likely to reduce a technological laggard's economic payoff (Deephouse, 1999; Graevenitz, 2005) to such an extent that the technological laggard is likely to engage in a different strategy that helps it to avoid the competition (Aghion *et al*., 2005; Macieira, 2006). A technological laggard, motivated by the desire to avoid the technology competition, is likely to move to a new position where the intensity of technology competition is lower.

# CHAPTER 3

## HYPOTHESES AND THEORY DEVELOPMENT

**Table 1. Theory bases overview.**

| **Hypothesis** | **Focus** | **Level** | **Theories** | **Elements** |
|---|---|---|---|---|
| H1: Distance to the technology frontier | Organizational capabilities | Firm | Capabilities approach | Routines, path dependency, and capability reconfiguration and transformation |
| H2: Innovation momentum | Organizational capabilities | Firm | Capabilities approach | Routines, path dependency |
| H3: Experience at the technology frontier | Organization capabilities | Firm | Capabilities approach | Routines, path dependency |
| H4: Prior window of competitive response | Economic incentives | Environment | Technology competition | Competitive response |
| H5: Competition in the current position | Economic incentives | Environment | Technology competition | Economic payoff |
| H6: Market share | Organization capabilities | Firm | Capabilities approach & Technology competition | Capabilities reconfiguration, economic payoff |
| H7: Innovation momentum and market competition | Organizational capabilities & Economic incentives | Firm & environment | Capabilities approach & Technology competition | Routines, economic payoff |

Table 1 provides an overview of the theories for hypothesis development. Drawing on the firm capabilities research, Hypotheses 1-3 propose that a technological laggard is likely to choose a strategic move that better utilizes its existing organizational capabilities. Drawing on the competitive dynamics research, Hypotheses 4-6 propose that a technological laggard is likely to seek a position in which it can extract a higher economic payoff.

In this study, a technological laggard can: *not move* from its current position, *move towards* the current technology frontier, or *move to* the technology frontier. Under the current format, a technological laggard has a probability of choosing from the three strategic alternatives. The probability of choosing a given strategic alternative is independent of that of choosing the other alternatives. The sum of three probabilities is equal to one. Hence, for instance, a higher probability of a technological laggard moving to the technology frontier decreases the probabilities of it not moving and moving towards the technology frontier.

The hypotheses incorporate relevant strategic alternatives when theoretical implications are available. Hence, of the three strategic alternatives available to technological laggards, some alternatives do not develop into a theoretical prediction for each hypothesis.

### 3.1 The Simple Effect: Firm-level

*Distance to the technology frontier*

**Figure 4. Illustration of a technological laggard's distance to the technology frontier.**

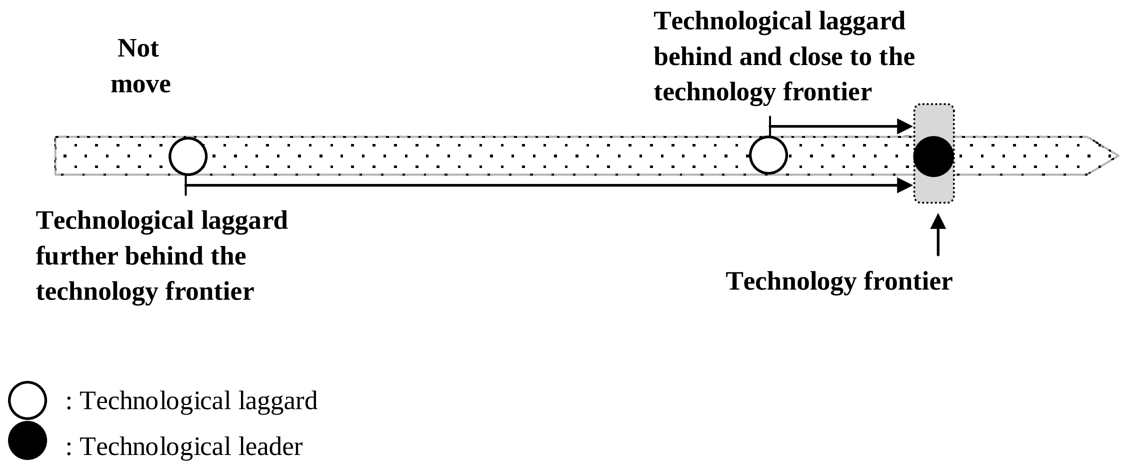



Figure 4 depicts the scenario where technological laggards are at various distances to the technology frontier. A technological laggard's organizational capabilities are a critical factor in determining its position in relation to the technology frontier. A technological laggard who can move towards or to the technology frontier typically has better technological capabilities, and the process of capability development involves achieving a balance of economic gains and costs.

First, for a technological laggard that is far behind the technology frontier, moving to the technology frontier usually requires it to improve its technological capabilities. Capability development can be costly (Ofek & Sarvary, 2003; Sudharshan *et al.*, 2006). Costs to develop organizational capabilities that are needed to move to the technology frontier usually increase with a technological laggard's distance behind the technology frontier (Bhattacharya *et al*., 1998; Boulding & Christen, 2008; Grenadier & Weiss, 1994). Second, the more distance there is between a technological laggard and the technology frontier, the more difficult for the technological laggard to develop needed technological capabilities in a short timeframe due to time compression diseconomies (Dierickx & Cool, 1989; Pacheco-de-Almeida, 2010) or to develop routines required for innovating the new technology that can push the technology frontier outward (Runde *et al*., 2008; Teece, 1980). Third, although market uncertainty at the technology frontier is high for most firms[9], it is even higher for a technological laggard. The further a technological laggard is behind the technology frontier, the less able it is to manage the market uncertainty because it has less or no experience at the technology frontier. Thus, market uncertainty at the technology frontier is even more likely to discourage a technological laggard from moving to the technology frontier (Pacheco-de-Almeida & Zemsky, 2003). Fourth, the competitive dynamics research suggests that moving to the frontier technology is a strategic action with high visibility (Aboulnasr *et al*., 2008; Barnett & McKendrick, 2004; Chen & Hambrick, 1995); and the move is especially likely to draw attention from the technological leader as the move usually occurs not far from its position. Hence, moving to the technology frontier is generally perceived to be more intimidating to the technological leader, prompting it to respond competitively to counter the move by rival firms (Baum & Korn, 1999; Lant & Baum, 1994; Porac *et al*., 1995). Furthermore, in addition to defending its market from the competition, a technological leader is also inclined to engage in competitive responses as a way to maintain its leadership status (Zahra, Nash & Bickford, 1995). Competitive responses from the technological leader are likely to reduce the economic payoff that a technological laggard anticipates to gain from moving to the technology frontier (Smith *et al*., 1997).

Taken together, the costs associated with moving to the technology frontier usually increase with a technological laggard's distance behind the technology frontier, hence lowering

[9] For instance, Eli Lilly introduces a supreme breakthrough insulin product in 1980 that receives poor market acceptance. Not only customers do not like it but retailers are also reluctant to add it to their already crowded shelf. Source: Eli Lilly and Company: Innovation in Diabetes Care, Harvard Business case 9-696-077 by C. M. Christensen, 2004

the anticipated economic payoff; economic payoff is likely to decrease due to competitive response. Therefore, the increases in a technological laggard's distance behind the technology frontier decrease its likelihood of moving to the technology frontier.

*Hypothesis $1_{move\ to}$: The further a technological laggard is behind the technology frontier, the less likely it will move to the technology frontier.*

If a technological laggard's likelihood of moving to the technology frontier decreases, its likelihood of choosing the other two strategic alternatives increases. I develop two sub-hypotheses that can help explain why the likelihood of a technological laggard not moving from its current position, and moving towards the technology frontier each increase with its distance behind the technology frontier.

By how much a technological laggard can move towards the technology frontier largely depends on its technological capabilities. First, moving towards, but not all the way to, requires a lower level of technological capabilities from a technological laggard than moving to the technology frontier, because technologies behind the technology frontier are generally less advanced (Jovanovic, 2009). Also, a technological laggard typically incurs lower costs when moving towards than to the technology frontier (de Figueiredo & Kyle, 2006; Markides & Geroski, 2005; Leiblein & Ziedonis, 2007), because costs involved in developing the same technology decreases with the number of prior deployments (Pacheco-de-Almeida & Zemsky, 2007; Ruiz-Aliseda & Zemsky, 2006). Additionally, more knowledge is generally available for less advanced technologies thanks to knowledge spillovers[10] from firms that have deployed the technology before (Eeckhout & Jovanovic, 2002; Jovanovic & MacDonald, 1994; McGahan &

[10] Knowledge spillovers can be an intentional strategic action by the technological leader, such as technology transfer in the form of licensing, joint venture, or alliances (Anand & Khanna, 2000; Asakawa, 2007; Hamel, 1991; Kale, Dyer & Singh, 2002). In that case, the technological leader decides when and what to transfer. Knowledge spillovers can be unintentional as well. The second mover advantage literature explains how late mover firms can learn from the experience of early mover firms (Dutta *et al*., 1995; Hoppe, 2000).

Silverman, 2006). Second, moving towards the technology frontier is generally less visible and not be perceived as intimidating to other rival firms than moving to the technology frontier, hence inviting fewer competitive responses from other technological laggards. A move towards the technology frontier is even less likely to receive competitive responses from the technological leader because such a move poses little threat to its leadership status. Third, a technological laggard who moves towards the technology frontier is likely to compete with a different type of rivals when moving to the technology frontier. The study into the ever-changing basis of competition suggests that a technological laggard selects a competition base where there are few direct rivals (Carroll, 1985). A technological laggard is likely to be more competitive if the selected base enables it to better utilize its resources (Baum, 1995; Baum & Korn, 1999). Because a technological laggard's resources and organizational capabilities are generally less specialized than the technological leader's, moving towards the technology frontier is therefore more likely to provide a better competition base that allows a technological laggard to show higher strength of competition than moving to the technology frontier (Baum, 1995; Brittain & Freeman, 1980). In sum, the greater the distance a technological laggard is behind the technology frontier, the more likely it chooses to move towards than move to the technology frontier due to the limitations of its organizational capabilities.

*Hypothesis* $1_{move\ towards}$*: The further a technological laggard is behind the technology frontier, the more likely it will move towards the technology frontier as opposed to moving to the technology frontier.*

A technological laggard that is far behind the technology frontier generally has inferior technological capabilities. The inferiority of its technological capabilities usually deters it from moving to a new position, mostly because the process of capability development can be very costly. Unlike a technological laggard who chooses to moves towards the technology frontier and as a result is generally required to innovate to keep up with the progression of the technology frontier (Adner & Kapoor, 2010; Hellwig & Irmen, 2001), a technological laggard can do little innovation to remain in its current position with little innovation (Alder, 2010; Beath, Katsoulacos & Ulph, 1987; Eggers, 2009). Moreover, capabilities of a technological laggard who is far behind the technology frontier are likely to further deteriorate because the technological laggard is not able to benefit from the knowledge spillovers occurring at/near the technology frontier (Jovanovic & Nyarko, 1996; Kafouros & Buckley, 2008; Khanna, 1995). A technological laggard's absorptive capacity is likely to dwindle as well because its limited access to the technology frontier (Cohen & Levinthal, 1990), *viz.* locked-out by its old technologies. Dwindling absorptive capacity typically increases a technological laggard's difficulty in improving its technological capabilities (Narasimhan *et al*., 2006). For a technological laggard who is far behind the technology frontier, it is likely to be even more difficult for it to move towards or to the technology frontier (Abernathy & Clark, 1985; Fudenberg *et al*., 1983; Mansfield, 1985). Even not moving to a new position, older technologies can still sell for an extended period (Adner & Kapoor, 2010). Therefore, a technological laggard's distance to the technology frontier increases with its likelihood of not moving from its current position.

> *Hypothesis* $1_{\text{not move}}$*: The further a technological laggard is behind the technology frontier, the more likely it will not move from its current position as opposed to moving to the technology frontier.*

*Innovation momentum*

The firm capabilities research suggests that a technological laggard's experience usually becomes one of the contributing factors that leads to the development of its organizational capabilities (Cyert & March, 1963; Greve, 1998b; King & Tucci, 2002). Hence, a technological laggard with experience of moving towards the technology frontier is likely to be more capable of repeating the move (Chen, Lin & Michel, 2010). Furthermore, a technological laggard that is capable of utilizing such organizational capabilities on a regular basis tends to exhibit higher innovation momentum that leads it to be more capable of, and hence is even more likely to move to a new position (Hutzschenreuter & Israel, 2009; Joshi, 2005; Kelly &Amburgey, 1991).

Given the importance of capability in competition, a technological laggard is more likely to respond with organizational capabilities that it utilizes on a regular basis (Cohen, March & Olsen, 1972; Pablo, 1994). Also, practices usually develop into routines. A technological laggard with experience of moving towards the technology frontier is likely to develop routines that can help it to achieve higher innovation momentum. Thus, the increase in a technological laggard's innovation momentum increases its likelihood of moving towards the technology frontier.

*Hypothesis 2$_{\text{move towards or to}}$: The greater a technological laggard's innovation momentum is, the more likely it will move towards or to the technology frontier as opposed to not moving from its current position.*

Hypothesis 2 posits that a technological laggard's experience is likely to be one of contributing factors that develops its organizational capabilities. Experience gained at the technology frontier is especially likely to develop capabilities that can make a technological laggard more competitive at the technology frontier.

*Experience at the technology frontier*

A technological laggard is likely to develop organizational capabilities in response to its experience gained in a certain environment (Adner &Kapoor, 2010; Ferrier, 2001; Robinson, Fornell & Sullivan, 1992). In considering whether to move to the technology frontier, a technological laggard is likely to choose a strategic move that can help increase the utility of its existing organizational capabilities (Grenadier & Weiss, 1997; Greves, 1998a; 1998b). First, a technological laggard with experience at the technology frontier is likely to develop organizational capabilities that can enable it to compete with technological leaders at the technology frontier (Eggers, 2012; Fanelli 2006; King & Tucci, 2002). For instance, a technological laggard with experience at the technology frontier typically knows the terms of competition because it has acquired that knowledge at the technology frontier from previous encounters with other rival firms (Koka & Prescott, 2008; Lant & Baum, 1994; Porac *et al*., 1995).

Second, a technological laggard's experience at technology frontier suggests that it had been a technological leader. The longer a technological laggard has held the position of technological leadership in the past, the more likely it sets regaining that position as its aspiration target (Baum & Korn, 1999; March, 1988; Lant, 1992). For a technological laggard who had been a technological leader before, its motivation to regain the leadership position is stronger, and it is likely to be more aggressive than other technological laggards who have never been a technological leader (Bowman, 1982; Baum *et al.*, 2005; March & Shapira, 1992). Hence, a technological laggard who has accumulated the more experience at the technology frontier is more likely to take even more risk in trying to move to the technology frontier.

*Hypothesis 3$_{move\ to}$: The more experience a technological laggard has at the technology frontier, the more likely it will move to the technology frontier.*

After analyzing firm-level characteristics that affect a technological laggard's likelihood of choosing one specific strategic alternative over the others, this study changes now broaden its scope of analysis to the environment-level. Hypothesis 4 and 5 each underscore the environmental influence on a technological laggard's likelihood of not moving from its current position, or moving to the technology frontier. This research highlights how a technological laggard's environment affects the anticipated economic payoff from innovation, which subsequently determines its strategic move.

*Prior window of competitive response*

**Figure 5. Illustration of prior window of competitive response (Time the first technological laggard took to move to the technology frontier).**

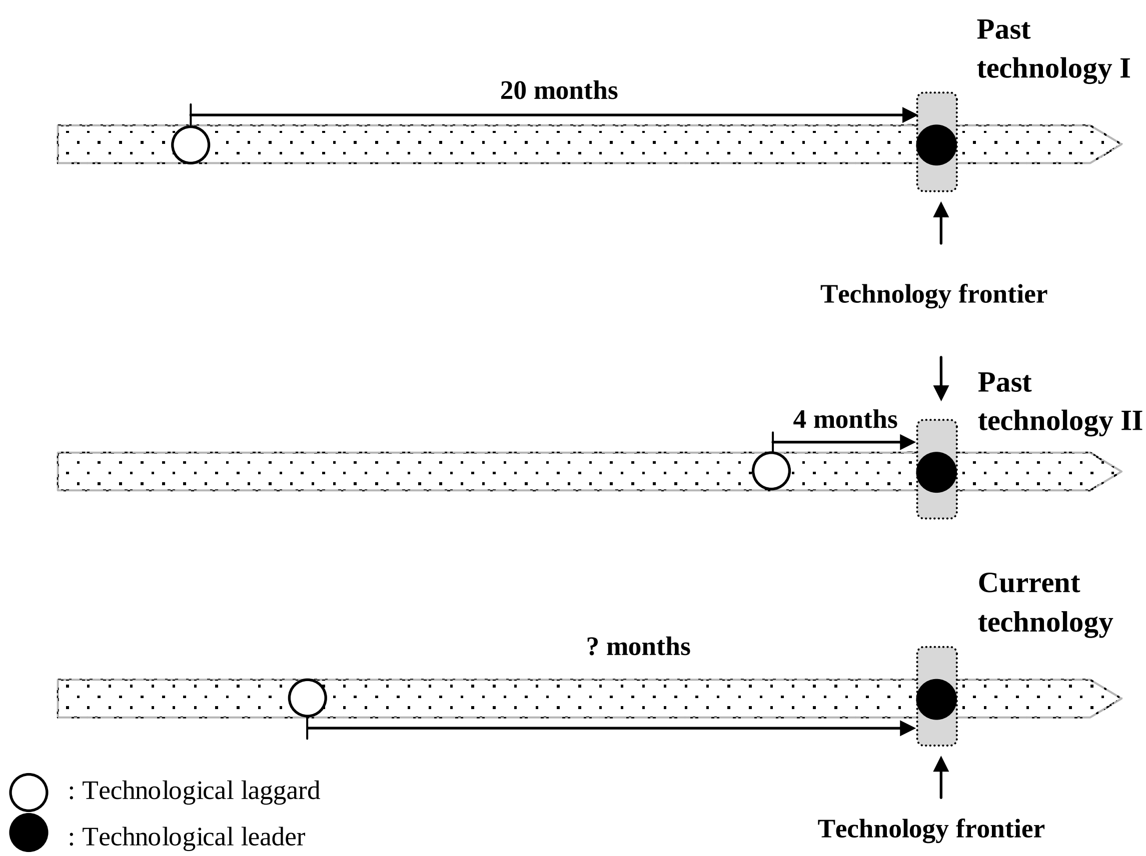


Figure 5 illustrates that a technological laggard first use the length of prior windows of competitive responses as a gauge before deciding whether to move to the technology frontier. A short window of competitive response from the prior most advanced technologies suggests that firms in the industry may have a higher tendency of moving to the technology frontier (Clark & Montgomery, 1998). First, the competitive dynamics research suggests that moving to the technology frontier is a visible action that usually invites competitive responses (Chen & Hambrick, 1995; Chen & Miller, 1994; Miller & Chen, 1994a; 1994b)[11]. A technological laggard and its rival firms are likely to have developed a process of "action-reaction" in which technological leadership changes hands constantly (Ali, 1994; Vickers, 1986). Second, the firm capabilities research suggests that there are firms capable of maintaining competitive parity (Jensen, 2003; Lieberman & Asaba, 2006). Technological leaders are more likely to initiate competitive responses because of their superior technological capabilities and the motivation to defend their reputation as a credible defender (Ailwadi, Lehmann & Neslin, 2001; Chen *et al.*, 1992).

Hence, a technological laggard is likely to anticipate better economic payoff if competitive responses occur more slowly (Hoppe, 2000; Katz & Shapiro, 1987; Lieberman & Montgomery, 1988). Therefore, the time it takes for competitive response to occur increases a technological laggard's likelihood of moving to the technology frontier.

*Hypothesis* $4_{move\ to}$*: The longer it has taken for any firm to respond to the advancing of the technology frontier in the past, the more likely a technological laggard moves to the technology frontier.*

[11] It is important to highlight the difference between game theory and the competitive dynamics research in terms of their use in this study. Game theory generally assumes that players have a perfect foresight and there are defined rules of game for players; while the competitive dynamics research does not maintain such an assumption.

In addition to prior window of competitive response, the competition in a technological laggard's current position is also likely to encourage it to move to a new position (Capron & Chatain, 2008).

*Market competition in the current market*

**Figure 6. Illustration of competition in positions.**

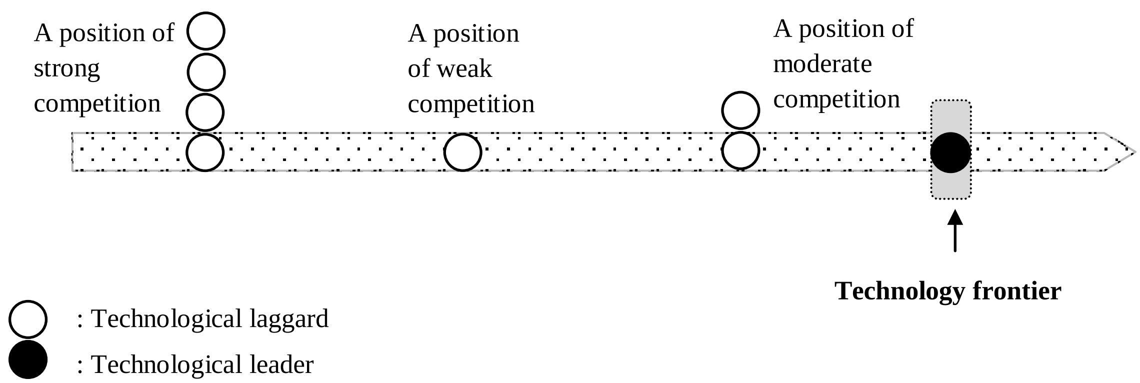



Figure 6 illustrates that intensity of market competition increases when there are more firms (Capron & Chatain, 2008; Kilduff *et al.*, 2010). Escalating market competition in the current market usually reduces a technological laggard's anticipated economic payoff from innovation if it remains in the current market (Fuentelsaz, Gomez & Polo, 2002)[12]. On the revenue side, a technological laggard is more likely to draw more aggressive competitive actions from its rivals as market competition intensifies (Baum & Korn, 1996; Chen & MacMillan, 1992; Chen *et al*., 2010). A technological laggard’s technology value is likely to be lower than

[12] There are several explanations as to why market competition can reduce a technological laggard's likelihood of moving to a new position. First, Vives' (2005) game-theoretic models suggest that market competition is likely to deter technology advancement mostly because firms have become more risk-averse. Hence, when the degree of market competition is high, not moving from the current position can be a technological laggard's decision in response to competition. Second, Chen (1996) discusses how rival firms' capabilities of initiating competitive responses affect the focal firm's competitive behavior. The focal firm may choose not to act if it lacks required capabilities, or if its rival firms possess superior capabilities. Because extant research literature (Barney, 1991; Roberts, 1999) suggests economic payoff as the main factor affecting a firm's competitive behavior, I decide to adopt the view of economic payoff to develop this hypothesis.

originally anticipated due to increasing market competition (Aghion, Harris & Vickers, 1997; Cotterill & Haller, 1992). Consequently, a technological laggard in a competitive market is likely to have lower revenue (Astley & Fombrun, 1983; Khandwalla, 1987; Stigler, 1964). On the cost side, intense market competition often increases the costs of a technological laggard, as a result of increasing difficulty in protecting its market resources from competition (Adner & Zemsky, 2005; Kilduff, Elfenbein & Staw 2010; Sirmon *et al.*, 2010), and acquiring new resources (Pfeffer & Salancik, 1978; Yasai-Ardekani, 1989).

Taken together, a technological laggard in an increasingly competitive market is likely to experience lower revenue and higher costs , resulting in a lower economic payoff (Gardner, 2005; Obloj & Capron, 2011; Young, Smith & Grimm, 1996). Decrease in a technological laggard's anticipated economic payoff increases its likelihood of moving to a new position (Khandwalla, 1973)[13].

*Hypothesis 5$_{move\ towards\ or\ to}$: The greater the market competition in a technological laggard's current market is, the more likely it will move towards or to the technology frontier as opposed to not moving from its current position.*

*Market share*

Hypothesis 6 emphasizes the influence of market share on a technological laggard's anticipated economic incentives, which then increase the likelihood of it not moving from the current position. A large market share typically increases a technological laggard's inertia, and places a constraint on its organizational resources[14] (Dutta *et al.*, 1995; Golder & Tellis, 1993;

[13] The current logic is comparable with the diversification literature's predictions and findings regarding lagging firms' innovation behavior. In order to avoid technology competition, a lagging firm can better appropriate the value of its technology by applying its existing knowledge and resources to other products (Miller, 2004).

[14] Although the extant research literature suggests that a market share may endow a firm with more resources, a big market share does not always lead to resources abundance. For instance, a firm often gains more market share at the

Lieberman & Montgomery, 1988; Mitchell, 1991; Tripsas & Gavetti, 2000). Hence, this dissertation posits that a large market share discourages a technological laggard from moving to the technology frontier.

A large market share usually reduces the economic payoff that a technological laggard anticipates moving to the technology frontier, mainly because of the following five reasons. First, a large market share typically requires more organizational resources from a technological laggard. Given that organizational resources are usually constant in the short run, moving to the technology frontier is likely to force a technological laggard to rearrange its resources, impairing its ability to manage its current market share. Even if sometimes a market share endows a firm with abundant resources, not all resources are for investments in innovating and not all innovations are for developing the most advanced technology. A technological laggard may have adequate resources when it moves to the technology frontier, but lack organizational capabilities to implement the move. Second, a large market share typically generates sizeable revenue which is likely to discourage a technological laggard from leaving its current position (Clark & Montgomery, 1998). Third, a technological laggard with a large market share usually reacts more slowly to competitive actions from rivals than one with a small market share due to inertia (Chen & Hambrick, 1995; Chen *et al.*, 1992). High inertia resulting from a large market share generally weakens a technological laggard's ability to manage competitive actions from rivals. High inertia usually leads a technological laggard to experience a more substantial erosion of its market share (Ferrier *et al.*, 1999). In effect, inertia sometimes can be a technological laggard's response to profit-maximization, even when such an action may lead to an organization's decline (Lieberman

expense of profitability (Armstrong & Collopy, 1996). When a firm sets maximizing market share as its top priority, it may gain more sales by cutting price (Venkatraman, 1989), or spending more on marketing and manufacturing (MacMillan and Day 1987), which can be detrimental to its profitability (and hence available resources). Further, a firm may not be able to maintain product quality during price war, resulting lower customer satisfaction, which can also damage its profitability (Anderson, Fornell & Lehmann, 1994; Fornell, 1992).

& Montgomery, 1988). Fourth, the preference for a less volatile environment can also discourage a technological laggard from trying to change the market's status quo (Ali 1994; Ferrier, 2001; Ferrier *et al.*, 1999; Reinganum, 1989), thereby precluding competitive actions from the rivalry. Fifth, a technological laggard with a large market share may too focus on fully utilizing its existing organizational capabilities to develop new routines (Leonard-Barton 1992; Sirmon *et al.*, 2007; Sirmon *et al.*, 2010); consequently, the technological laggard is unable to leverage the existing organizational capabilities to manage market uncertainty that may result from moving to the technology frontier (Gilbert & Newbery, 1982; Reinganum, 1989). To move to the technology frontier, a technological laggard is required to have organizational capabilities that can facilitate its innovation (Chandy & Tellis, 2000)[15]. Without the required capabilities, a technological laggard is less likely to move to the technology frontier. Collectively, the greater the market share a technological laggard has, the less inclined it is towards innovating (Czarnitzki & Kraft 2004). A low level of organizational resources and capabilities that are needed to manage technology and market competition further deters a technological laggard from moving to the technology frontier[16].

*Hypothesis* $6_{move\ to}$: *The greater a technological laggard's market share, the less likely it will move to the technology frontier.*

[15] Chandy and Tellis (2000) maintain that a firm is less vulnerable to technological inertia if it develops market and technological capabilities that are apt to facilitate radical innovation. However, compared with the technological leader, a technological laggard is less likely to develop the required capabilities due to lower exposure to the technology frontier, and it may be less than willing to develop the required capabilities, simply because those required resources are not really necessary for its current operation.

[16] The scope of theoretical implications of market share may go beyond organizational capabilities. In fact, Bronnenberg, Dhar and Dube (2009) suggest that entry order and organizational capabilities both affect a firm's market share. The authors call for the distinction between "early-entry effect" and "marketing competence." This dissertation follows the economic aspect of market share that the anticipated economic payoff is a critical factor in influencing a firm's technology deployment decision (Gilbert, 2006).

### 3.2 Complete model: The firm- & environment- effect

*Innovation momentum and market competition*

Competitive dynamic research suggests that market competition in the current market makes it more difficult for a technological laggard to maintain its market position (Grossman & Mendoza, 2003; Priem, 2007; Rao & Drazin, 2002). The firm capabilities research suggests that a technological laggard with innovation momentum is more likely to move to a new position. Taken together, the innovation momentum is likely to positively moderate the relationship between market competition and a technological laggard's likelihood of moving to a new position. The market competition is more likely to trigger a technological laggard to move to a new position if it has greater innovation momentum.

*Hypothesis 7$_{\text{move to or towards}}$: As a technological laggard's innovation momentum increases, the positive effect of market competition on its likelihood of either moving towards or to the technology frontier becomes stronger.*

**Table 2. Hypothesis summary.**

| | **Element** | **Level of analysis** | **Theory basis** | **Hypothesis** |
|---|---|---|---|---|
| Hypothesis $1_{\text{move to}}$ | Distance | Firm | Organizational capabilities | The further a technological laggard is behind the technology frontier, the less likely it will move to the technology frontier |
| Hypothesis $1_{\text{move towards}}$ | Distance | Firm | Organizational capabilities | The further a technological laggard is behind the technology frontier, the more likely it will move towards the technology frontier as opposed to moving to the technology frontier |
| Hypothesis $1_{\text{not move}}$ | Distance | Firm | Organizational capabilities | The further a technological laggard is behind the technology frontier, the more likely it will not move from its current position as opposed to moving to the technology frontier |
| Hypothesis $2_{\text{move towards or to}}$ | Innovation momentum | Firm | Organizational capabilities | The greater a technological laggard's innovation momentum is, the more likely it will move towards or to the technology frontier as opposed to not moving from its current position |
| Hypothesis $3_{\text{move to}}$ | Experience at the technology frontier | Firm | Organizational capabilities | The more experience a technological laggard has at the technology frontier, the more likely it will move to the technology frontier |
| Hypothesis $4_{\text{move to}}$ | Prior window of competitive response | Environment | Competition | The longer it has taken for any firm to respond to the advancing of the technology frontier in the past, the more likely a technological laggard moves to the technology frontier |
| Hypothesis $5_{\text{move towards or to}}$ | Market competition in the current market | Environment | Competition | The greater the market competition in a technological laggard’s current market is, the more likely it will move towards or to the technology frontier as opposed to not moving from its current position |
| Hypothesis $6_{\text{move to}}$ | Market share | Firm | Organizational capabilities & competition | The greater a technological laggard’s market share, the less likely it will move to the technology frontier |
| Hypothesis $7_{\text{move to or towards}}$ | Innovation momentum & market competition | Firm & environment | Organizational capabilities & competition | As a technological laggard’s innovation momentum increases, the positive effect of market competition on its likelihood of either moving towards or to the technology frontier becomes stronger |

Table 2 summarizes all hypotheses.

# CHAPTER 4

# EMPIRICAL SETTING

## 4.1 Why the Flat Panel Display Industry

This dissertation uses the flat panel display industry as an empirical setting. Some research studies have adopted the flat panel display industry mainly for the purpose of studying innovation (Eggers, 2009; Linden *et al.*, 1997; Mathews, 2003; 2004; 2005; Spencer, 2003). The flat panel display industry provides several empirical advantages to testing hypotheses in this dissertation. First, the flat panel display industry is one of the fastest growing industries. The fast pace in innovation enables researchers to collect a larger amount of data in a relative short period of time. Every plant that produces flat display panels has a generation. The industry's first generation plant was built in 1990. The size of mother glass substrate at the time was 30cm x 40cm (≈11.8” x 15.7”), which is equivalent to the size of an open fashion magazine[17]. Today, an 8.5th generation plant, which has become the main production force, produces the size of mother glass substrate at approximately 220cm x 250cm (≈86.6” x 98.4”), equivalent to the size of a pool table. The flat panel makers have economic incentives to process increasingly large-sized mother glass substrates due to strong demand for large-sized display that cathode ray tube (CRT) and other older generations of display technologies cannot offer. Within a relatively short period of time, the advancement of technological specifications from generation to generation has provided us with ample opportunities to observe the strategic moves made by technological leader and laggards (Christensen, 1997; Cho *et al.,* 1998).

Second, the dimension of a firm’s technological capabilities is relatively clear. A firm's technological capabilities of producing flat panel displays are its most advanced generation of

[17] AUO Online: Technology (http://www.auo.com/?sn=188&lang=en-US)

plants. A higher generation plant can process a larger mother glass substrate; the later section 'size matters!' I explain why the ability to manufacture a large mother glass substrate is both technologically and economically critical in the flat panel display industry. The ability to produce large size panels is a common index for a flat panel maker's technological capabilities. Thus, the most advanced generation of plants offers an empirical approach to approximate the flat panel maker's technological capabilities, and to define the technology frontier.

Third, a higher generation plant can process a glass substrate of a larger size, which is divided into display panels later in the process. A large glass substrate can either produce a display panel of a larger size, which commends a higher price margin, or yields more display panels, achieving economies of scale. Hence, moving to the technology frontier occurs frequently in this industry (Linden *et al.*, 1997). Since the inception of the flat panel display industry, technological laggards have each taken turns developing the most advanced technology for each generation. The first laboratory prototype was produced in the United States[18] in 1972. Matsushita Electric and Toshiba were both among the first firms to begin mass production and putting their American counterparts behind the technology frontier in 1991 (Mathews, 2005). The competition further intensified after Samsung and LG joined the industry in 1994. The technological leader and laggards have surpassed each other more frequently since early 2000.

Fourth, the process of manufacturing flat panel displays requires constant innovations. With the rapid pace of technology advancement, there are a good number of firms stationed at different distances to the technology frontier, providing variances with respect to firms' strategic moves.

[18] Brody, T.P., 1997, *Birth of the Active Matrix,* Information Display, Vol. 13, No. 10, p. 28-32.

*A brief history of the flat panel display industry*[19]

**Figure 7. The evolution of the flat panel display industry.**

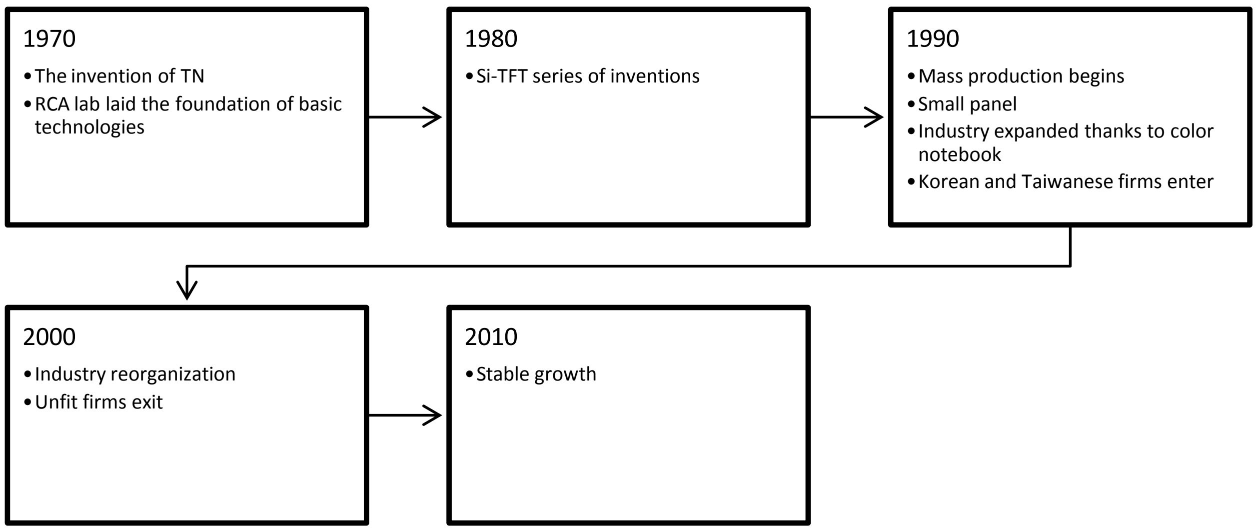



Figure 7 illustrates the growth of the flat panel display industry over the years. Technological innovation dominants almost exclusively in the earlier periods, and market development has become more important as the industry evolves. I provide details of technology and market development in each decade since the birth of display technology.

The 1960s is a decade in which substantial technology advancement occurred in the flat panel display industry. The inventions of today's dominant technologies all take place in this decade. In 1960, RCA Sarnoff Research Center discovers the substance of liquid crystal which scatters light when it is in a transparent state. This discovery is among one of the first key findings that eventually leads to corporate interests in the flat panel display industry. In 1964, RCA creates an image-capable display. In the same year, the University of Illinois' Computer-based Education Research Lab develops an alternating current plasma display panel. In 1967,

[19] Murtha, Lenway & Hart (2001) is the main citation source for this section.

Westinghouse creates thin-film transistors (TFT), the dominant technology widely used in today's flat panel display. In 1968, RCA introduces its liquid crystal display at a press conference in New York City. In the same year, Westinghouse develops an active matrix electroluminescent display. In 1969, the researchers from Kent State University invent a twisted-nematic liquid crystal display (TN LCD).

The 1970s features a decade of entries by Japanese firms and exits by American firms. In 1970, RCA first begins licensing its liquid crystal technology to Sharp. In 1971, Westinghouse researchers develop an active matrix liquid crystal display for U.S. Air Force. In 1973, Sharp introduces the first handheld calculator using the LCD technology; Seiko Epson introduces the first digital watch using the LCD technology; IBM utilizes results from their joint program with the University of Illinois and starts to manufacture small monochrome plasma display panels (PDPs); two years later, IBM constructs a plant that builds larger PDPs in Kingston, New York. RCA and Westinghouse end their flat panel display program in 1974 and in 1978, respectively.

The 1980s is a decade full of excitement. A greater extent of commercialization and mass production rolls out in this decade, and supporting industries has played a significant role. Seiko has a TFT LCD television in its lab in 1982, introduces a prototype in 1983, and starts marketing a 2-inch TFT LCD television in 1984. In 1986, Matsushita introduces a 3-inch TFT LCD television; Sharp begins mass-production of STN LCD for laptop screens. Also in 1986, IBM ends its plasma production and enters a joint R&D with Toshiba to develop TFT LCD. Starting in 1987, Sharp mass produces small panels for 3 to 4-inch TFT LCD television. In 1989, Corning, who supplies mother glass substrate to flat panel display makers, and Applied Materials, who is a supplier of equipment for panel manufacturing, begins to develop specialized products for buyers from the flat panel display industry.

The 1990s is a tough decade for Japanese and American makers because of financial crisis and rival entry. In 1990, NEC builds the first generation 1 (Gen1) TFT LCD production line. In 1991, Sharp follows the suit and constructs its 1st generation plant for mass-production of large-format color TFT LCD. In 1992, the industry experiences shortages after IBM introduces the first laptop[20] with a color TFT LCD. In 1994, Sharp begins its 2nd generation TFT LCD production line. In 1995, Samsung and LG each enter the industry with 2nd generation plants. In 1997, the financial crisis upsets Japanese and Korean makers. The capital shortage leads Japanese makers to license technologies to Taiwanese makers, officially making the entry by Taiwanese makers in the industry in late 1990s. LG receives capital from and forms a joint venture with Philips. Also in 1997, Samsung's 3rd generation plant achieves commercial yields. In 1999, LG.Phillips begins operations. In the same year, Samsung and LG.Philips surpass Japanese makers to become industry leaders.

The 2000s is a decade of growth and increasing rivalry. The market value of flat panel display industry grows from $24 billion in 2000 to $95 billion in 2008. The TFT LCD has become 'the' technology for flat panel display, while OLED is steadily increasing its market share every year[21]. The applications for flat panel display have grown considerably. On top of laptop and digital watch, in-vehicle display, mobile phone screen, handheld devices, large televisions, and other products have also fueled the stronger demand for flat panel displays. In addition to Japanese and Korean makers, Taiwanese and Chinese makers enter the industry in tandem. In a couple of years, Taiwanese makers in total have accounted for more than 40% of the total global large size (≥10-inch) TFT LCD shipment; while Japanese makers claim 12%. Samsung and LG.Philips have been able to achieve a stronger leadership position by aggressive

[20] This model is IBM ThinkPad Model 700C

[21] Hsieh, D., Globalization of Display Industry, DisplaySearch Asia Round Table Forum, 2005

investment made over years, while the Japanese and Taiwanese makers have been lacking in this regard.

*The evolution of display technology*

This section provides a briefly review on the current and future commercialized display technologies. The CRT was the major technology before the rise of flat panel display in 1990s. Liquid crystal display (LCD) has been the dominant flat panel display technology due to in large part to the promotion by Japanese flat panel display makers in 1980s.

**Figure 8. The technologies for producing flat panel display.**

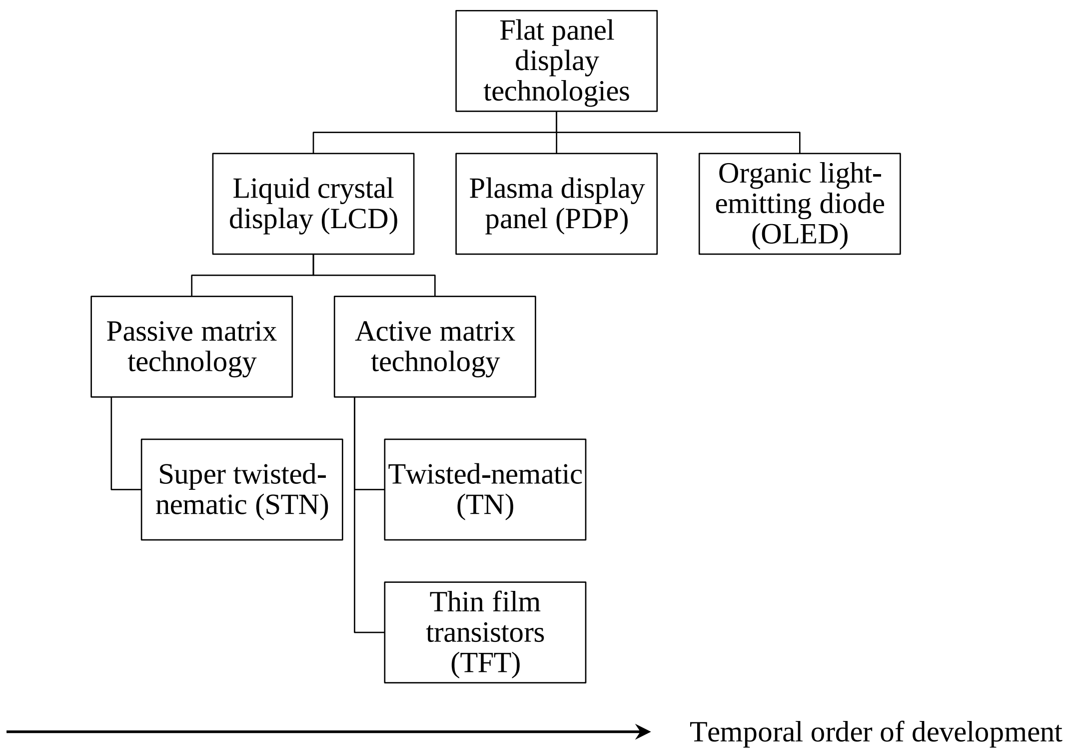



Figure 8 shows the dominant commercialized technologies for flat panel display. The five major commercialized technologies are, in the order of development, super twisted-nematic (STN), twisted-nematic (TN) , thin film transistors (TFT), plasma display panel (PDP), and organic light-emitting diode (OLED). STN technology adds colors to a panel by adding internal filters. Display adopting STN technology usually has very long response times and poor contrast ratio, which are very typical of passive matrix technologies. STN are often the technology used in manufacturing older laptop screens and weight scale displays. Display for more recent laptop screens and televisions utilize active matrix technologies. TFT is probably the most widely adopted active matrix technologies. Displays using TFT have brighter and sharper image quality and shorter response times. Besides TFT, TN is another common active matrix technology, where the control of voltage twists liquid crystal elements at varying degrees to block or pass the light. Because it is made with a different mechanism from LCD, PDP has been the dominant technology in producing large flat display panels. OLED is likely to be the next dominant display technology after LCD. The OLED technology initially supplies the market of with small size displays, and gradually increases its panel size to enter the market of median size display.

*Working principal of flat panel display: Size matters!*

A brief introduction to the mechanism[22] of flat panel display is helpful to understand why flat panel display makers' race to build higher generation plants. Each flat panel display is divided from a piece of glass substrate. A large size of glass substrate means more panels per glass substrate and better economies of scale, which is why moving to higher generation plant is so important to flat panel display makers[23].

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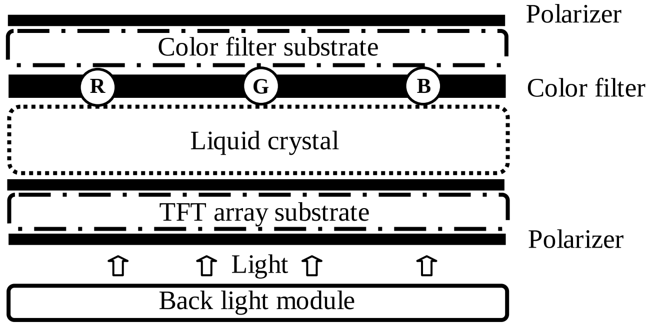
[22] The key technological information sources in this section are AU Optronics (www.auo.com), LD Display (www.lgdisplay.com), and Wikipedia (en.wikipedia.org/wiki/Plasma).

[23] A glimpse into the flat panel market by Ed Hall (SEMI) and Charles Annis (DisplaySearch) (http://www.semi.org/en/About/SEMIGlobalUpdate/Articles/P037787)

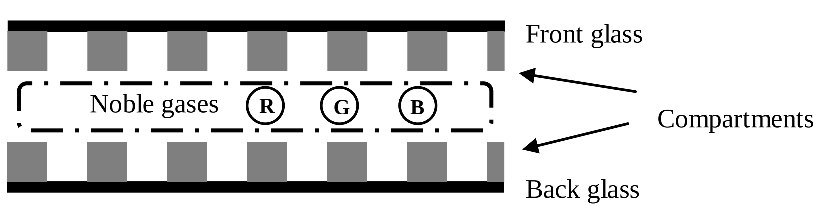
TFT LCD




Three key components of TFT LCD are back light module, TFT array, and color filter. Back light module is the source of light (Ukai, 2007; Lin, Chen & Huang, 2004). Thin film transistor is printed on TFT array substrate. The application of voltage changes the direction of liquid crystal, which controls the path that light passes through. The color filter controls which colors to be shown. The loss of light from emitting out of backlight module to color filter substrate is around 85%. The thickness of a TFT LCD panel is about 3 to 4 nm.

The technology used in printing thin film transistor explains the limited size of display (Kelly, 2000). First, in order to have a glass substrate ready for printing, the evenness of glass substrate is critical. The larger the glass substrate, the more uneven the surface becomes. Second, before the printing takes place, the glass substrate needs to go through several rounds of chemical vaporization and etching. A large piece of the glass substrate typically has lower yield.

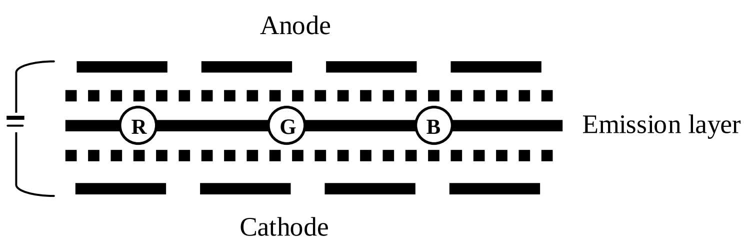
PDP




In terms of manufacturing large size display, PDP has a significant advantage because it uses an entirely different mechanism to control light path (Kelly, 2000). The plasma display panel is made of two panels of glass, and there are thousands of compartments in between those two panels. These compartments hold noble gases and mercury. The noble gases form into plasma when voltage is applied to these compartments. The changes in energy level of different phosphor painted in the compartments results in plasma, giving off visible different lights.

Because PDP does not require printing circuits on a substrate like TFT, PDP is far more suitable for displays of a much larger size. The largest PDP has a size of 103 inches. The technological drawbacks for PDP include hefty weight, energy inefficiencies, and fading colors once noble gases begin to dissipate.

OLED




Originally conceived as a different invention than TFT, OLED can function without backlight module (Kelly, 2000). Layers of organization materials consist of OLED (Nieto, 2005). Upon the application of voltage, a current of electrons from anode and cathode from two outer layers flows to the center, forming an exited state in the emission layer. The emission of radiation with a frequency that is in the visible region occurs when the exited state decays. The layer of OLED requires organic vaporization and the use of excimer laser, which place a constraint on the size the panel can grow.

Among the next generation of technologies, OLED seems to be the most promising one for the following reasons (Crawford, 2005). First, it is very thin, less than 1 nm thick. Compared with TFT, it is brighter, has a sharper contrast, faster response speed, and wider viewing angle.

Its low-power consumption feature is a highly desirable one because the handheld devices using the OLED technology can last much longer than others. The most acclaimed feature of OLED is its flexibility. An OLED display can be bended like a piece of paper. This flexibility allows for a broader range of applications of OLED technology, such as e-paper.

*Technical and financial difficulties in growing panel size*[24 25]

There are at least five major technical difficulties in manufacturing large glass substrates[26]. First, it is difficult to lock in the yields at the same level across the board, especially for glass substrate of smaller sizes at the early stage of production. Second, glass substrates move in between work stations throughout the manufacturing process. The larger the glass substrates are, the heavier they tend to be; the difficulties involved in transporting glass substrates between work stations increase with the size and weight of glass substrate. Third, the manufacturing equipment may very well become a problem as panels grow larger in size. More R&D resources need to be relocated to compensate for the lack of manufacturing equipment. Fourth, manufacturing process itself becomes more challenging when glass substrates grow larger in size. For example, the time required for filling liquid crystal into panels increases with the size of glass substrate[27], and the defect rate also increases due to uneven filling. Fifth, the size of some components, such as back-light module and mother glass, increases with the size of panel. The transportation of these components is likely to make logistics more difficult when their size increases.

[24] Hoetker (2005; footnote 6)

[25] Iwai, Y., 2002, The Key Components, Materials, and Skills of Flat Panel Display, Kogyo Chosakai Publishing Co., Ltd, Japan

[26] Tian, M., 2008, The development of flat panel display, Wu-nan, Taipei, Taiwan

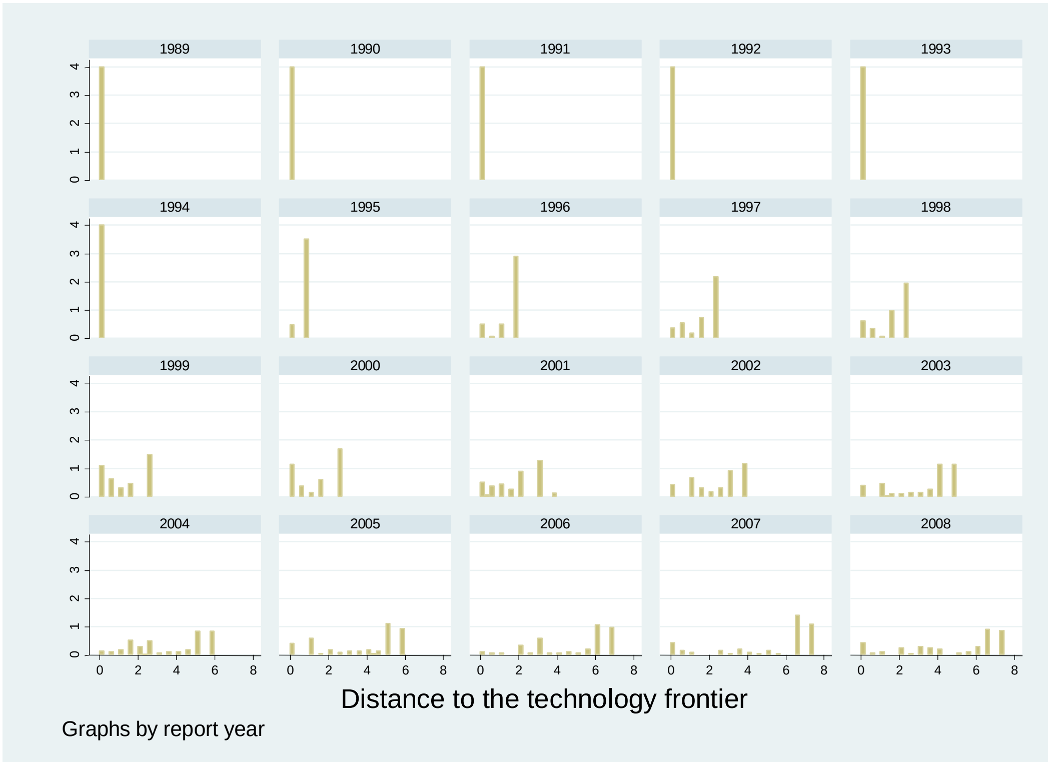
[27] Shih, W., Shih, C., Wang, J., & Yu, H., 2010, Harvard Business case: Chi Mei Optoelectronics, p.9

At least three additional major financial difficulties exist for manufacturing large glass substrates. First, more capital expenditure is required. The costs of building a latest generation plant are about $4 billion dollar, which is only one-third of the total costs. Not only is the required capital outlay high, the difficulty in achieving a decent return on investment is high as well. Second, the takt time, the gap in time between transitions from one work station to another, increases with the size of glass substrate. More idling time from the production line means more loss in efficiency and therefore less cost saving. Third, the manufacturing of large glass substrates requires more floor space. As a result, a larger, and hence more expensive, plant needs to be built to provide needed floor space.

Despite the aforementioned technological and financial challenges, flat panel display makers still manage to grow the panel size (Kelly, 2000; Tian, 2008). There are at least two economic incentives associated with large display panels. First, the demands and profit margins for large displays are higher. Technologically, CRT cannot produce a monitor larger than 50 inches; but the flat panel display technology makes possible the production of large size display, up to 103 inches. The birth of large size display creates a new demand for large television set and outdoor display. Second, panel makers can achieve economies of scale faster by processing one large mother glass substrate and then dividing it into multiple smaller panels later on than staring with only one small glass substrate that can only produce one single panel[28]. Producing large size panels can help flat panel display makers achieve better economics of scope as a large mother glass subtract can be cut into various panels sizes for different product applications.

[28] AUO Online: http://auo.com/?sn=442&lang=en-US

**Figure 9. The distribution of distances to the technology frontier across years.**




As seen in Figure 9, there are more technological laggards increasing their distances to the technology frontier from year to year. This trend corroborates Aghion *et al.* (2005) and Khanna (1995) that technology competition is likely to result in long-tailed distribution of distance between the technological leader and laggards. While the technological leader and some technological laggards with superior technological capabilities innovate to deploy more advanced technologies, some technological laggards with inferior technological capabilities cluster at the tail end. The more the technology advances beyond the technology frontier, the more a technological laggard's distance grows.

# CHAPTER 5

# QUANTITATIVE ANALYSIS

This chapter presents the quantitative portion of my research. I begin by first describing the data and variables that test the hypotheses developed in Chapter 3. I then discuss the econometrics model that I use, the results I obtain from it, and post-hoc analysis I carry out.

## 5.1 Data Description

The primary data sources are 1) the 1991, and 1996-2008 issues of Flat Panel Display Applications--Trends and Forecasts by a Japanese research firm, and 2) and the 1991-2009 annual reports on the flat panel display industry from Taiwan's Photonics Industry & Technology Development Association. These reports contain the product sales and production information for worldwide flat panel makers. Every annual issue provides production information for each flat panel maker in the world. The report includes plant generation, manufacturing technology, plant capacity, plant commencement date, size of panels produced, and transaction history if the plant has sold or ceased operation. Supplementary data sources include the Delphion database which provides makers' patenting activity, makers' annual reports, and news coverage from LexisNexis, Digital Times, Korea Times, The Nikkei Weekly.

There are five types of technology used in manufacturing flat panel displays-- super twisted-nematic (STN), twisted-nematic (TN) , thin film transistors (TFT), organic light-emitting diode (OLED), plasma display panel (PDP). Given the technological similarities in STN, TN, and TFT, these three technologies are grouped into one LCD technology group, along with PDP & OLED technology groups. There are 148 technological laggard firms in the dataset. This yields a total of 536 firm-year observations.

## 5.2 Variables and Measures

### Table 3. Variables summary and their definition.

| Variable | Empirical proxy | Variable definition |
|---|---|---|
| Dependent variable | | |
| Strategic alternatives | Three strategic moves | It contains three categories: not move, move towards, move to the technology frontier (year, by technology). |
| Independent variables | | |
| H1: Distance to the technology frontier | Generation difference | The generation of the industry's latest plant minus the generation of the focal technological laggard's most advanced plant (year, by technology) |
| H2: Innovation momentum | Number of moves | The number of plants of higher generations that has been built (years, by technology) |
| H3: Experience at the technology frontier | Days spent at the technology frontier | The sum of days that the focal technological laggard has spent at the technology frontier, i.e., having the industry's latest generation plant (year, by technology) |
| H4: Prior window of competitive response | Time difference | Of each generation, the commencement date difference between the first plant that adopts the generation and the second plant that adopts the same or newer generation (year, by technology), mean-centering. |
| H5: Market competition in the current market | The sum of plants | The sum of rivals' plants of the same generation that the focal technological laggard shares (year, by technology). |
| H6: Market share | Market share | Total production value of the focal technological laggard divided by total production value of the industry (year, by technologies) |
| H7: Innovation momentum* Market competition | Innovation momentum*market competition | Innovation momentum*market competition, following their prior definitions |
| Control variables | | |
| Interfirm relationships | Relationship counts | The number of interfirm relationships that the focal technological laggard has with other rival firms, including technology transfer, technological licensing, cross licensing, plant sold, joint venture, and alliance (year) |
| Industry growth | Percentage increase in industry production value | Annual percentage change of sum of production value of all firms in the industry (year, by technology) |

**Table 3 (cont.)**

| Variable | Empirical proxy | Variable definition |
|---|---|---|
| Firm age | Years spent since the entry | Current year minus the year when the focal technological laggard built its first plant (year, by technology) |
| Firm size | Production value | The focal technological laggard's production value (year, by technology) |
| Technology frontier competition | Number of firms | The number of firms at the technology frontier (year, by technology). |
| Patent stock | Patent counts | The total number of patents that the focal technological laggard has had since its inception (year). |
| Recent move | Dummy | The number of years since the focal technological laggard has built a plant of higher generation (year, by technology). |
| Current generation | Generation | The current most advanced generation of plant that the focal technological laggard operates (year, by technology). |
| Number of plants | Number of plants | The number of plants owned by the focal technological laggard (year, by technology). |
| Number of generations moved | Generation difference | The generation difference between the focal technological laggard's current most advanced plant and last most advanced plant (year, by technology). |

Table 3 summarizes the conceptual variables and the operationalization of empirical data for hypothesis testing.

*Dependent variable*

In this dissertation, a technological laggard can have three strategic alternatives, which correspond with three categories of dependent variable. A technological laggard can choose to *not move* from its current position, *move towards*, or *move to* the technology frontier. The first category, the empirical operation considers a technological laggard *not moving* from its current position if the generation of its leading plant is the same from last year, and the generation of this leading plant is lower than the latest generation in the industry.

Second category, a technological laggard *moves toward* the technology frontier when it builds a new plant whose generation is less advanced than the most advanced plant of the same technology. The operationalization considers a technological laggard moving toward the technology frontier when its leading plant has a higher generation than its prior plants from the last year, but has a lower generation than the industry's latest plant.

Third category, the operationalization considers a technological laggard *moving to* the technology frontier when it builds a plant that has an equal or higher generation than the industry's current latest plant.

I forward the dependent variable by one year because the actual implementation of a technological laggard's plan may occur sometime after the initial decision is made.

*Independent variables*

Hypothesis 1: Distance to the technology frontier

The generation of a technological laggard's most advanced plant provides a proper measure of its technological capabilities. In order to manufacture a larger flat display panel and have cost advantage, a technological laggard needs a plant of higher generation, which requires better technological capabilities to build and operate. Hence, the highest generation defines the technology frontier in the industry. The distance to the technology frontier is the difference in generation between a technological laggard's and the industry's.

the generation of a technological laggard's most advanced plant serves as a suitable proxy for its technological capabilities.

Hypothesis 2: Innovation momentum

Innovation momentum is defined as a consistent pattern of moving to higher generations. The measure of a technological laggard's innovation momentum is the count of plant generation changes that a technological has had since its inception (Chen *et al.*, 2010).

Hypothesis 3: Experience at the technology frontier

Experience at the technology frontier is the number of days that a technological laggard has zero distance to the technology frontier. That is, the number of days that a technological laggard's most advanced generation is equal to the leading generation in the industry.

A short prior window of competitive response suggests that the first firm that adopts the latest generation plant is soon followed by another firm in adopting the same or next generation of technology. A prior window of competitive response is defined as the difference in the number of commencement months between the first plant that adopts the latest generation and the second plant that adopts the current latest or next generation of technology.

Hypothesis 4: Prior window of competitive response

A short prior window of competitive response means the technological leader soon has another firm achieving the same level of technology as it does. A prior window of competitive response is, per each latest generation, the difference in the number of months between the first plant's commencement date and the second plant, or the difference in the number of months between the first plant commencement date and the current and next generation. Of the two temporal gaps, the shorter one is the empirical proxy for prior window of competitive response. This variable is mean-centering, by year and by technology.

Hypothesis 5: Market competition in the current market

Market competition typically increases when more firms adopt the same technology (Adner & Snow, 2010; Ali, 1994). Market competition in the current market is defined as the sum of rivals' plants with which a technological laggard has shared the same generations (Aiken & West, 1991; Lerner, 1997; Shan, 1990).

Hypothesis 6: Market share

The market share is a firm's annual production value of a given technology divided by the industry's total production value in the same year, of the same technology Eggers (2009).

*Control variables*

The control variables include interfirm relationships, industry growth, firm age, firm size, technology frontier competition, patent stock, recent move, current generation, number of plants, and number of generation moved.

Interfirm relationships

Interfirm relationships count the number of deals (including technological licensing, cross-licensing, plant sold, joint venture, and alliance) that a technological laggard has with rival firms in a given year. The interfirm relationship is likely to affect the value that is appropriable from rival firms' innovation and the value of the focal firm's innovation (Dyer & Singh, 1998; Singh & Mitchell, 2005).

Industry growth

Industry growth may affect a technological laggard's behavior in technology competition (Derfus *et al.*, 2008). Annual percentage change of the sum of production value for all firms in the industry is the measure of industry growth for each technology. The composition of market share in a mature industry may be different than market share in a nascent industry (Lumpkin & Dess, 2001; Mazzucato & Semmler, 1999), necessitating the control of industry growth.

Firm age

A technological laggard's experience is likely to affect its capability of managing technology competition, and its absorptive capacity to new technological knowledge. Age is operationalized as the number of years that have passed since the technological laggard established its first plant in the flat panel display industry.

Firm size

Given that a large technological laggard can anticipate higher economic gains through commercializing the innovation, this study controls *production value* that a technological laggard has as a proxy for firm size.

Technology frontier competition

If there are already a number of firms at the technology frontier, a technological laggard might not be as inclined to move to the technology frontier. Hence this study controls the number of firms currently at the technology frontier.

Patent stock

Patent counts (in 100) often serve as a proxy for a firm's ability to innovate (Kim & Vonortas, 2006; Sakakibara & Branstetter, 2001; Somaya, 2003). The proxy for a technological laggard's ability to innovate is the number of patents that it has been granted since the firm birth. The patents are limited to the section of F21V, G02F, G09G, G09F, H01J, H01L, H04N, H05B, H05H under international patent class (Hoetker 2001; Spencer, 1997).

Recent move

Recent move is the number of years that have passed since the last plant built by a technological laggard. A recent new plant is likely to financially influence a technological laggard's next technology deployment decision, and leads to some adjustment in its product portfolio (Lee *et al.*, 2011; Livengood & Reger, 2010; Tang, 1988).

Current generation

The independent variable as represented by distance to the technology frontier is a relative term. Even though the distance is equal to one, the interpretation can be very different when the most advanced generation is G9 than when the most advanced generation is G2. In order to address this omission, the model controls for the generation of a technological laggard's most advanced plant.

Number of plants

Given that a higher number of plants can lead to better economies of scale and scope, a technological laggard is therefore more likely to achieve higher return on innovation. This study adds the number of plants that a technological laggard has in a given year and for a given technology to control for the efficiency effect (Adner & Zemsky, 2005; Demsetz, 1973; Mas-Ruiz & Ruiz-Moreno, 2011; Szymanski, Bharadwaj, & Varadarajan, 1993).

Number of generations moved

The independent variable *innovation momentum* measures how many times a technological has moved. This measure treats each move equally even when some moves span more generations than others. In order to compensate for this omission, the model controls for the difference in generation by each move.

### 5.3 The Multinomial Logistic Model

The multinomial logistic model is suitable for testing the hypotheses in this study because a technological laggard has three alternative moves available to it (Greene, 2007: 859)[29]. The dependent variable consists of *j* strategic moves, and the regressors consist of independent variables and a constant that represent a technological laggard *i*'s organizational and environmental characteristics. The model omits the error term $\varepsilon_i$ because it performs estimation. The multinomial logistic model for a technological laggard's choice of strategic moves can be expressed as follows,

$$Prob(Y_i = j) = \frac{e^{\beta_{0i}+\beta_k x_i}}{\sum_{k=0}^{J} e^{\beta_{0i}+\beta_k x_i}}, j = 0, 1, \dots, J.$$

The multinomial logistic model gives an estimation of probabilities of J+1 strategic moves for a technological laggard with $x_i$ characteristics. Greene (2007: 860) suggests a simpler model that assumes the constant term $\beta_0$=0 after normalization. Hence, the multinomial logistic model that estimates probability of a technological laggard *i*'s *j* strategic move is,

$$Prob(Y = j) = \frac{e^{\beta_k x_i}}{1 + \sum_{k=1}^{J} e^{\beta_k x_i}}, for\ j = 1, \dots, J,$$

$$Prob(Y = 0) = \frac{1}{1 + \sum_{k=1}^{J} e^{\beta_k x_i}}.$$

*Prob(Y=0)* is the baseline model, and *J=0* is the baseline category. Of the dependent variable, the strategic moves *j* where *j=1, 2, ..., J* pair with the baseline category. The statistical interest is to find out the probabilities of a technological laggard *i* with certain characteristics $x_i$ choosing a

[29] In my conversation with a manger from the flat panel display industry, he points out that, when determining whether to build a new plant, his firm first considers the major rival firms' potential move. For instance, AUO first speculates whether Samsung's, its major rival, new plant will be the industry's next generation. Assuming that Samsung moves to the next generation, how should AUO enact its plant building plan accordingly. Therefore, this decision process is more akin to one-stage scenario where all alternatives are available at the same time. A multinomial logistic model is thus considered a more suitable model to simulate manager's decision process.

specific strategic move *j* over the baseline category (*J=0*). Given that a technological laggard can choose its strategic move from category *j* (*j=1, 2, ..., J*) or category (*J=0*), there is the log odds that the choice is *j*. The baseline-category logistic model (Agresti, 2007:174) with regressor:

$$\log\left(\frac{\pi_j}{\pi_{J=0}}\right) = \log\left(e^{\beta_j x_i}\right) = \beta_j x_i, j = 1, 2, \ldots, J-1$$

Each category *j* (*j=1, 2, ..., J-1*) has their baseline-category logistic model. Hence there are J-1 equations, and the predicted log odds vary with models. In order to compare two estimated probabilities of two categories other than the baseline category, the logistic model for comparing an arbitrary pair of category 1 and 2 is (Agresti, 2007: 174),

$$\log\left(\frac{\pi_1}{\pi_2}\right) = \log\left(\frac{\pi_1/\pi_J}{\pi_2/\pi_J}\right) = \log\left(\frac{\pi_1}{\pi_J}\right) - \log\left(\frac{\pi_2}{\pi_J}\right) = (\beta_2 - \beta_1)x_i$$

The above equation reports that the difference of estimated probabilities between category 1 and 2 for a technological laggard *i* is $(\beta_2 - \beta_1)x_i$.

Because of panel dataset, the multinomial logistic model for hypothesis testing specifies the standard errors that allow for intra-group correlation. Thus, within group observations may not necessarily have independency, whereas between group observations still maintain independency[30].

The use of multinomial logistic model requires a critical assumption-- independence of irrelevant alternative (IIA) property (Hausman & McFadden, 1984). Essentially, the likelihood that a technological laggard chooses a given move should be independent of the likelihood that it may choose other moves. Therefore, the multinomial logistic model should pass the test of IIA first before further testing. The statistical method used in verifying IIA assumption estimates for the unconstrained model and the constrained model. The unconstrained model *u* and constrained

[30] Stata 11 base reference manual, Vol. 3

model $c$ have $\beta$ 's and covariance's to calculate test statistics: $(\beta_c - \beta_u)'[cov(\beta_c) - cov(\beta_u)]^{-1}(\beta_c - \beta_u)$ .

**Table 4. IIA assumption test results.**

| Unconstrained model vs. | Constrained model I (excluding "not moving") | Constrained model II (excluding "moving towards") | Constrained model III (excluding "moving to") |
|---|---|---|---|
| $\lambda^2_{k=34}$ | 10.866 | 0.2416 | 353.12 |
| p-value | 0.9999 | 1 | $9.78e^{-53}$ |

The null hypothesis is that IIA assumption is not violated (Hausman & McFadden, 1984; McFadden, 1987; Small & Haiao, 1985). Table 4 reports the test statistics and their p-value. IIA assumption is held for not moving and moving towards groups, but the assumption is rejected for moving to group. Given that the null hypothesis is rejected, I then perform regression on the same dataset using multinomial probit which does not require IIA assumption. Because the results from both multinomial probit model and multinomial logistic model are the same[31], I still rely on multinomial logistic model as my main choice of statistical testing model.

[31] The output of multinomial probit model is in Robustness check section.

**Table 5. Summary statistics.**

| | Variable | | Count | Mean | S.D. | Min | Max | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A technological laggard's move | | 548 | 1.2 | 0.46 | 1 | 3 | 1 | | | | |
| 2 | Interfirm relationships | | 680 | 0.01 | 0.09 | 0 | 1 | -0.04 | 1 | | | |
| 3 | Industry growth | | 680 | 0.22 | 0.17 | -0.1 | 0.49 | -0.06 | -0.03 | 1 | | |
| 4 | Firm age | | 663 | 5.56 | 4.39 | 0 | 19 | -0.15 | 0.02 | 0.1 | 1 | |
| 5 | Firm size | | 680 | 390.04 | 868.39 | 0 | 8076 | 0.29 | 0.05 | 0.13 | 0.12 | 1 |
| 6 | Technology frontier competition | | 680 | 2.37 | 1.58 | 1 | 6 | 0.06 | 0.04 | -0.63 | -0.11 | -0.06 |
| 7 | Patent stock | | 677 | 741.83 | 1915.54 | 1 | 13997 | 0.04 | 0.14 | 0.05 | 0.16 | 0.3 |
| 8 | Recent move | | 680 | 3.57 | 3.88 | 0 | 18 | -0.13 | -0.02 | 0.01 | 0.41 | -0.21 |
| 9 | Current generation | | 633 | 1.88 | 1.1 | 1 | 8 | 0.08 | 0.07 | 0.16 | 0 | 0.55 |
| 10 | Number of plants | | 592 | 2.43 | 2.26 | 1 | 15 | 0.18 | 0.08 | 0.08 | 0.23 | 0.57 |
| 11 | Number of generations moved | | 549 | 0.15 | 0.43 | 0 | 2.5 | -0.06 | -0.03 | 0.07 | -0.01 | 0.13 |
| 12 | Distance to the technology frontier | H1 | 633 | 3.46 | 2.12 | 0.2 | 7.5 | -0.22 | -0.05 | 0.16 | 0.29 | -0.28 |
| 13 | Innovation momentum | H2 | 680 | 2.06 | 1.36 | 1 | 10 | 0.08 | 0.04 | 0.15 | 0.4 | 0.44 |
| 14 | Experience at the technology frontier | H3 | 680 | 270.44 | 539.71 | 0 | 2556 | 0.1 | -0.03 | 0.07 | 0.39 | 0.28 |
| 15 | Prior window of competitive response | H4 | 633 | 36.96 | 92.69 | -111.33 | 167 | -0.12 | -0.01 | -0.02 | -0.06 | -0.14 |
| 16 | Market competition in the current market | H5 | 633 | 71.97 | 36.08 | 3 | 179 | 0.05 | 0.08 | 0.13 | 0.29 | 0.25 |
| 17 | Market share | H6 | 680 | 0.01 | 0.02 | 0 | 0.19 | 0.39 | 0.03 | -0.02 | 0.05 | 0.8 |

**Table 5 (cont.)**

| | Variable | | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | A technological laggard's move | | | | | | | | | | | | | |
| 2 | Interfirm relationships | | | | | | | | | | | | | |
| 3 | Industry growth | | | | | | | | | | | | | |
| 4 | Firm age | | | | | | | | | | | | | |
| 5 | Firm size | | | | | | | | | | | | | |
| 6 | Technology frontier competition | | 1 | | | | | | | | | | | |
| 7 | Patent stock | | 0.02 | 1 | | | | | | | | | | |
| 8 | Recent move | | -0.1 | -0.08 | 1 | | | | | | | | | |
| 9 | Current generation | | -0.06 | 0.32 | -0.52 | 1 | | | | | | | | |
| 10 | Number of plants | | 0.03 | 0.27 | -0.19 | 0.39 | 1 | | | | | | | |
| 11 | Number of generations moved | | 0.02 | -0.03 | -0.39 | 0.37 | 0.23 | 1 | | | | | | |
| 12 | Distance to the technology frontier | H1 | -0.41 | -0.22 | 0.46 | -0.44 | -0.33 | -0.23 | 1 | | | | | |
| 13 | Innovation momentum | H2 | -0.06 | 0.22 | -0.34 | 0.54 | 0.54 | 0.34 | -0.21 | 1 | | | | |
| 14 | Experience at the technology frontier | H3 | -0.02 | 0.12 | -0.06 | 0.24 | 0.22 | 0.08 | -0.2 | 0.4 | 1 | | | |
| 15 | Prior window of competitive response | H4 | -0.06 | -0.27 | -0.15 | -0.07 | -0.12 | -0.02 | 0.24 | 0.03 | 0.19 | 1 | | |
| 16 | Market competition in the current market | H5 | -0.06 | 0.08 | -0.07 | 0.07 | 0.64 | 0.17 | 0.03 | 0.56 | 0.16 | 0.05 | 1 | |
| 17 | Market share | H6 | 0.06 | 0.3 | -0.19 | 0.36 | 0.55 | 0.13 | -0.43 | 0.33 | 0.22 | -0.17 | 0.22 | 1 |

### 5.4 Hypothesis Testing Results

Table 5 reports summary statistics[32].

**Table 6. Number of observations of technological laggard's strategic moves (forwarded by one year), by dominant technology.**

| | | Technology | | | |
|---|---|---|---|---|---|
| | | LCD | OLED | PDP | Total |
| Strategic moves | Not move | 513 | 36 | 9 | 558 |
| | Move towards | 100 | 9 | 8 | 117 |
| | Move to | 17 | 2 | 4 | 23 |
| | Total | 630 (90.26%) | 47 (6.73%) | 21 (3.01%) | 698 (100%) |

From Table 6, LCD is the most popular technology for producing flat panel displays during the observation period 1991 to 2008. LCD technology subgroup includes 90% of total observations, indicating that the LCD technology is the dominant technology for the flat panel display industry. Given the distinct technological characteristics and development path between LCD and other technologies as well as the dominance of the LCD (Eggers, 2009), I decide to test hypotheses with observations from the LCD technology, and save the observations from OLED for later robustness check.

[32] The correlation between market share and distance behind the technology frontier (*viz.* organizational capabilities proxy) is 0.33, corresponding with the theoretical implication that the market share is beyond organizational capabilities.

**Table 7. Moves by technological laggards across year.**

| Year | Not move | Move towards | Move to | Total |
|---|---|---|---|---|
| 1995 | 22 | 2 | 2 | 26 |
| 1996 | 25 | 6 | 1 | 32 |
| 1997 | 31 | 5 | 4 | 40 |
| 1998 | 29 | 8 | 0 | 37 |
| 1999 | 40 | 4 | 1 | 45 |
| 2000 | 37 | 7 | 3 | 47 |
| 2001 | 41 | 5 | 1 | 47 |
| 2002 | 42 | 10 | 1 | 53 |
| 2003 | 50 | 9 | 1 | 60 |
| 2004 | 61 | 5 | 0 | 66 |
| 2005 | 62 | 6 | 1 | 69 |
| 2006 | 58 | 9 | 1 | 68 |
| 2007 | 44 | 8 | 1 | 53 |
| Total | 542 | 84 | 17 | 643 |

Before reviewing the findings from hypothesis testing, I first provide the dynamics of the flat panel display industry with respect to the popularity of three moves-- *not move*, *move towards*, and *move to* the technology frontier. Table 7 reports counts corresponding with each strategic move. Note that the observation years in the current data range from 1989 to 2008. The flat panel display industry before 1995 has only Gen 1 plants. Thus, by the definition of technological leader and laggards in the current study, firms before 1995 are all considered technological leaders and hence are not reported in Table 7.

**Table 8. Multinomial logistic results**--Simple models (LCD technology only)

| | | Base: Not move | | Base: Move toward | | Base: Move to | |
|---|---|---|---|---|---|---|---|
| | | **Model 1a** | **Model 1b** | **Model 2a** | **Model 2b** | **Model 3a** | **Model 3b** |
| | | **Move towards** | **Move to** | **Not move** | **Move to** | **Not move** | **Move towards** |
| Interfirm relationships | | -12.37*** | -7.463*** | 12.37*** | 4.911*** | 7.463*** | -4.911*** |
| | | (-19.54) | (-4.74) | (19.54) | (3.43) | (4.74) | (-3.43) |
| Industry growth | | -0.286 | -2.740 | 0.286 | -2.454 | 2.740 | 2.454 |
| | | (-0.32) | (-0.75) | (0.32) | (-0.67) | (0.75) | (0.67) |
| Firm age | | -0.186** | -0.768** | 0.186** | -0.582* | 0.768** | 0.582* |
| | | (-3.18) | (-3.27) | (3.18) | (-2.54) | (3.27) | (2.54) |
| Firm size | | 0.000159 | 0.0000545 | -0.000159 | -0.000104 | -0.0000545 | 0.000104 |
| | | (0.86) | (0.19) | (-0.86) | (-0.52) | (-0.19) | (0.52) |
| Technology frontier competition | | 0.125 | -0.248 | -0.125 | -0.372 | 0.248 | 0.372 |
| | | (1.15) | (-0.48) | (-1.15) | (-0.71) | (0.48) | (0.71) |
| Patent stock | | 0.00000454 | -0.000202 | -0.00000454 | -0.000207 | 0.000202 | 0.000207 |
| | | (0.06) | (-1.16) | (-0.06) | (-1.18) | (1.16) | (1.18) |
| Recent move | | -0.0744 | 0.427+ | 0.0744 | 0.502* | -0.427+ | -0.502* |
| | | (-1.27) | (1.72) | (1.27) | (1.99) | (-1.72) | (-1.99) |
| Current generation | | -0.352+ | -1.049* | 0.352+ | -0.697 | 1.049* | 0.697 |
| | | (-1.65) | (-2.52) | (1.65) | (-1.63) | (2.52) | (1.63) |
| Number of plants | | 0.142* | 0.454** | -0.142* | 0.312* | -0.454** | -0.312* |
| | | (2.11) | (3.26) | (-2.11) | (2.57) | (-3.26) | (-2.57) |
| Number of generations moved | | -1.630*** | -0.0770 | 1.630*** | 1.553+ | 0.0770 | -1.553+ |
| | | (-3.69) | (-0.09) | (3.69) | (1.93) | (0.09) | (-1.93) |
| Distance to the technology frontier | H1 | 0.248* | -2.603** | -0.248* | -2.851** | 2.603** | 2.851** |
| | | (1.97) | (-3.03) | (-1.97) | (-3.19) | (3.03) | (3.19) |
| Innovation momentum | H2 | 0.289+ | 1.071* | -0.289+ | 0.782 | -1.071* | -0.782 |
| | | (1.77) | (2.00) | (-1.77) | (1.54) | (-2.00) | (-1.54) |
| Experience at the technology frontier | H3 | 0.000649* | 0.00180* | -0.000649* | 0.00115 | -0.00180* | -0.00115 |
| | | (2.35) | (2.57) | (-2.35) | (1.51) | (-2.57) | (-1.51) |
| Prior window of competitive response | H4 | -0.00369* | -0.000149 | 0.00369* | 0.00354 | 0.000149 | -0.00354 |
| | | (-2.00) | (-0.02) | (2.00) | (0.47) | (0.02) | (-0.47) |
| Market competition in the current market | H4 | 0.00233 | -0.0282*** | -0.00233 | -0.0305*** | 0.0282*** | 0.0305*** |
| | | (0.45) | (-3.48) | (-0.45) | (-3.39) | (3.48) | (3.39) |
| Market share | H6 | 17.71 | 24.86 | -17.71 | 7.145 | -24.86 | -7.145 |
| | | (1.41) | (1.62) | (-1.41) | (0.83) | (-1.62) | (-0.83) |
| Constant | | -1.996* | 3.126 | 1.996* | 5.123* | -3.126 | -5.123* |
| | | (-2.32) | (1.35) | (2.32) | (1.99) | (-1.35) | (-1.99) |
| Observations | | 536 | 536 | 536 | 536 | 536 | 536 |
| Pseudo $R^2$ | | 0.2712 | 0.2712 | 0.2712 | 0.2712 | 0.2712 | 0.2712 |

*z* statistics in parentheses

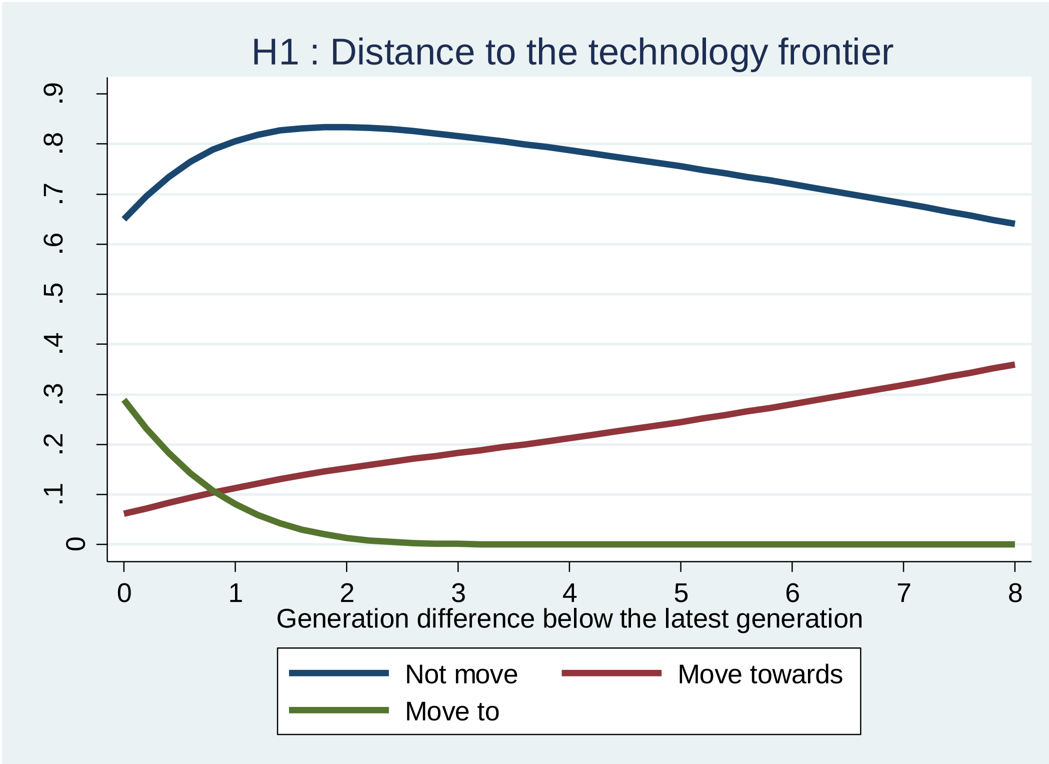
$^{+}$ $p < 0.1$, $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

Table 8 present the results of multinomial logistic regression, with the dependent variable as a technological laggard's alternative moves—*not moving* from its current position, *moving towards*, or *moving to* the technology frontier.

The dependent variable has multiple categories. Each multinomial model chooses one category as a base group, and examines whether a given group is more likely to be selected by the focal firm than the base group. For instance, Model 1a and Mode lb assume 'not move' as the base group. A positive (negative) coefficient indicates that the focal firm is more (less) likely to select an alternative move (e.g., 'moving towards' or 'moving to') than the base group (e.g., not moving).

In Table 8, Models 1-3 report the results of hypothesis testing. Figures 10-15 are model estimation. I explain the finding of each hypothesis using supporting figures.

**Figure 10. Model prediction for Hypothesis 1.**

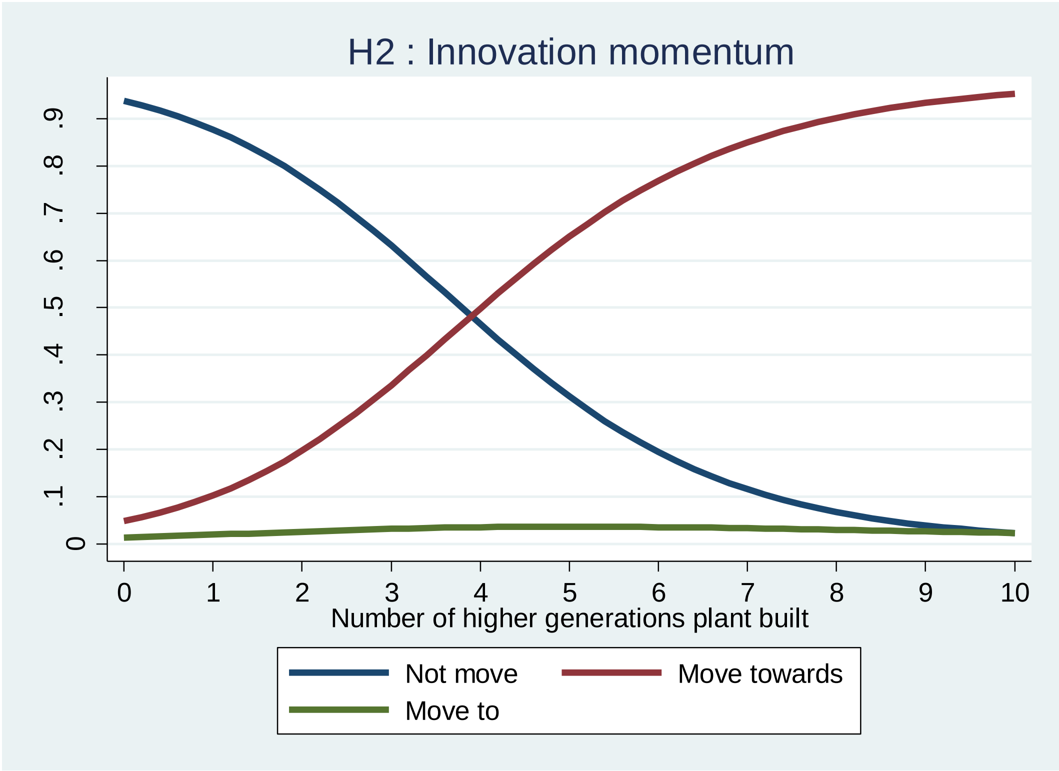



As $H1_{move\ to}$ proposed, a technological laggard further behind the technology frontier is less likely to move to the technology frontier. Model 3 provides the statistical support. In Figure 10, a laggard's probability of moving to the technology frontier decreases with its distance.

As $H1_{move\ towards}$ proposed, a technological laggard further behind the technology frontier is more likely to move towards the technology frontier as opposed to moving to the technology frontier. Model 2 provides the statistical support. In Figure 10, a laggard's probability of moving towards the technology frontier increases with its distance to the technology frontier.

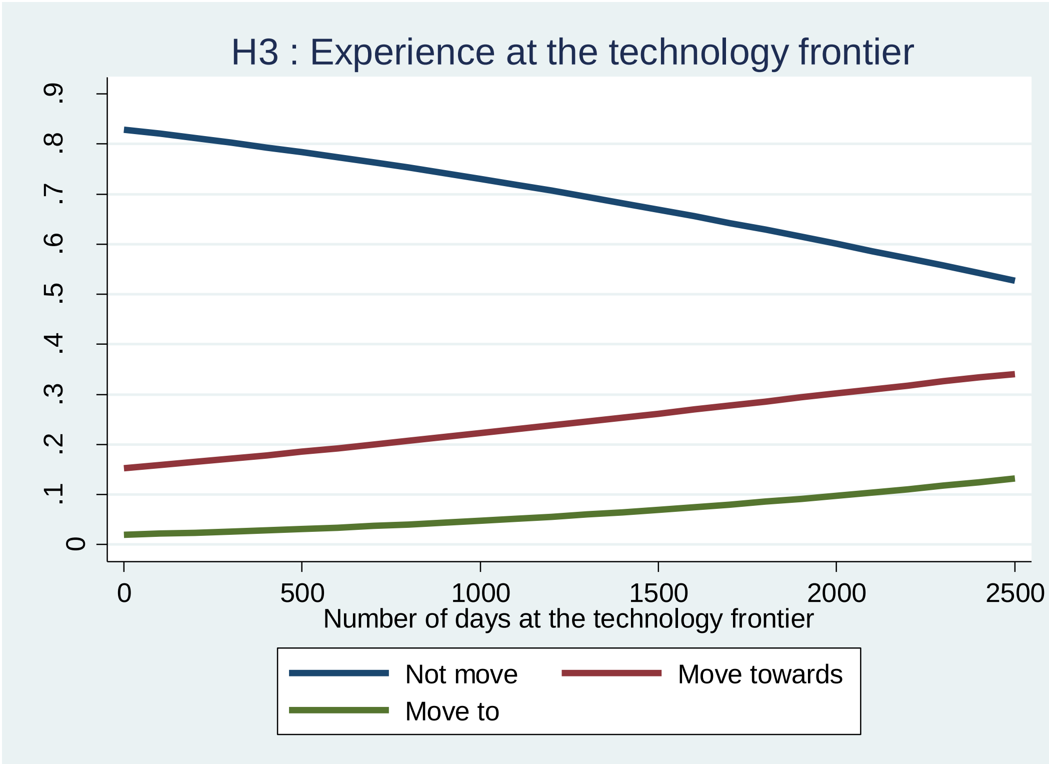
As $H1_{not\ move}$ proposed, a technological laggard further behind the technology frontier is more likely to not move from its current position as opposed to moving to the technology frontier. Model 1 provides the statistical support. In Figure 10, a laggard's probability of not moving from the current position increases with its distance when it is relatively close to the technology frontier.

**Figure 11. Model prediction for Hypothesis 2.**



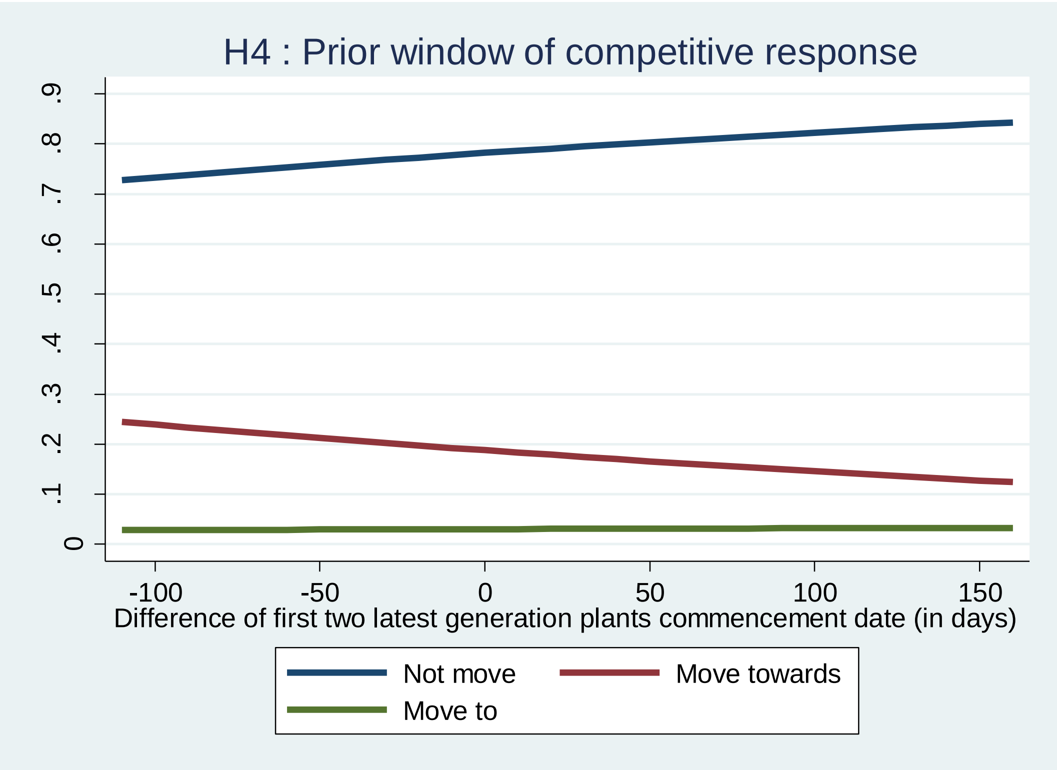

As H2$_{\text{move towards or to}}$ proposed, a technological laggard with higher innovation momentum is more likely to move to a new position. Model 1 provides the statistical support. In Figure 11, a technological laggard with higher innovation momentum is more likely to move towards or to the technology frontier.

**Figure 12. Model prediction for Hypothesis 3.**




As H3$_{\text{move to}}$ proposed, a technological laggard with experience at the technology frontier is more likely to move to the technology frontier. Model 1 provides the statistical support. In Figure 12, a laggard's probability of moving to the technology frontier increases with its experience at the technology frontier.

**Figure 13. Model prediction for Hypothesis 4.**




Hypothesis $4_{\text{move to}}$ suggests that a technological laggard is more likely to move to the technology frontier when the prior window of competitive response increases. Model 3 fails to support this hypothesis. The hypothesis testing results suggest that prior window of competitive response has *no* effect on a laggard's likelihood of moving to the technology frontier. Figure 13 shows post-estimation of Model 3.

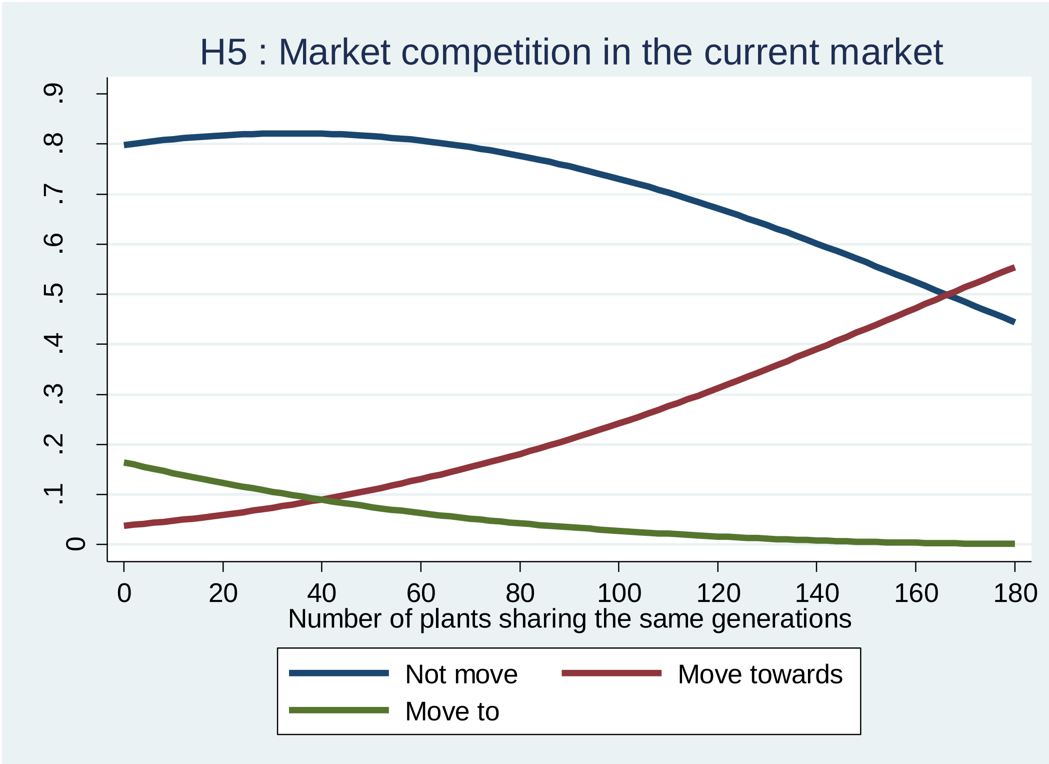
One possible explanation is that technological laggards in the flat panel display industry have a better mechanism to predict when the next generation plant will be in service. Like Moore's law in the semiconductor industry, Nishimura's law in the flat panel display industry predicts that the size of glass substrate grows 1.8 times in every three years[33]. The size of glass substrate has been growing at rate that Nishimura's law predicts for the past 20 years. Thus, the

[33] Tian M., 2008, Technical Development of Flat Panel Display, Wunan Book Co., Ltd, Taipei, Taiwan.

existence of a better mechanism weakens the argument for using the prior window of competitive response to predict the progression of the technology frontier.

Another possible explanation, the length of window may not be wide enough to allow a technological laggard to appropriate enough economic rents to justify the costs of moving to the technology frontier. In the current dataset, the maximum window is 167 days above the average length of window of competitive response. In the flat panel display industry, 167-day window is unlikely to allow a technological laggard to appropriate enough economic rents. Thus I conclude that the current dataset may not have enough variance on prior window of competitive response to test Hypothesis 4.

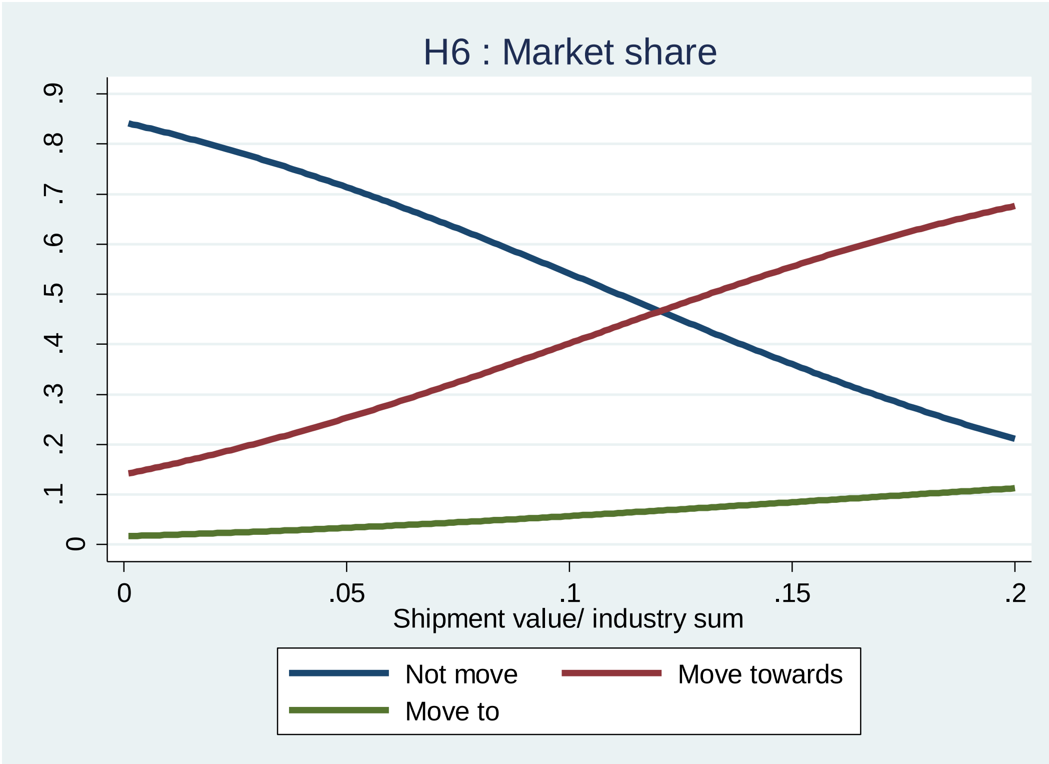
**Figure 14. Model prediction for Hypothesis 5.**




Hypothesis $5_{\text{move towards or to}}$ suggests that a technological laggard in a competitive market is likely to move to a new position. Model 1 fails to provide statistical support. Contrary to the hypothesis, a technological laggard is less likely to move from its current position when market competition in its market increases. Figure 14 provides a graphical illustration. Indeed, managers may be motivated, but are not able to move to a new position due to resource limitation (Zajac & Kraatz, 1993). Not only does an action without sufficient organizational support have a higher likelihood of failure, it is also likely to adversely affect its current operation.

Notably, the findings from Model 3 suggest that, if a technological laggard moves to a new position, it is more likely to move towards than to the technology frontier. The theoretical interpretation is that moving towards typically contains lower risk than moving to the technology frontier.

**Figure 15. Model prediction for Hypothesis 6.**




Hypothesis $6_{move\ to}$ suggests that a technological laggard with a greater market share is less likely to move to the technology frontier. Model 1 fails to support this hypothesis. The findings from Model 1 suggest that a technological laggard with a greater market share is *more* likely to move to the technology frontier. In Figure 15, a laggard's probability of moving the technology frontier increases with market share, and its probability of not moving decreases.

A possible explanation for the trends in Figure 6 is that return on innovation is likely to increase with market share (Mas-Ruiz & Ruiz-Moreno, 2011; Szymanski *et al*., 1993; Tang, 2006). In the process of building a newer generation plant, a number of investments are at fixed costs. A technological laggard may have a better chance of recouping its investments if it has a greater market share (Blundell *et al*., 1999; Demsetz, 1973; Mas-Ruiz & Ruiz-Moreno, 2011). A large market share usually has a positive effect on innovation output (Lunn & Martin, 1986).

Thus, a laggard with a greater market share has a higher probability of moving to the technology frontier.

**Table 9. Multinomial logistic results**--Complete models (LCD technology only)

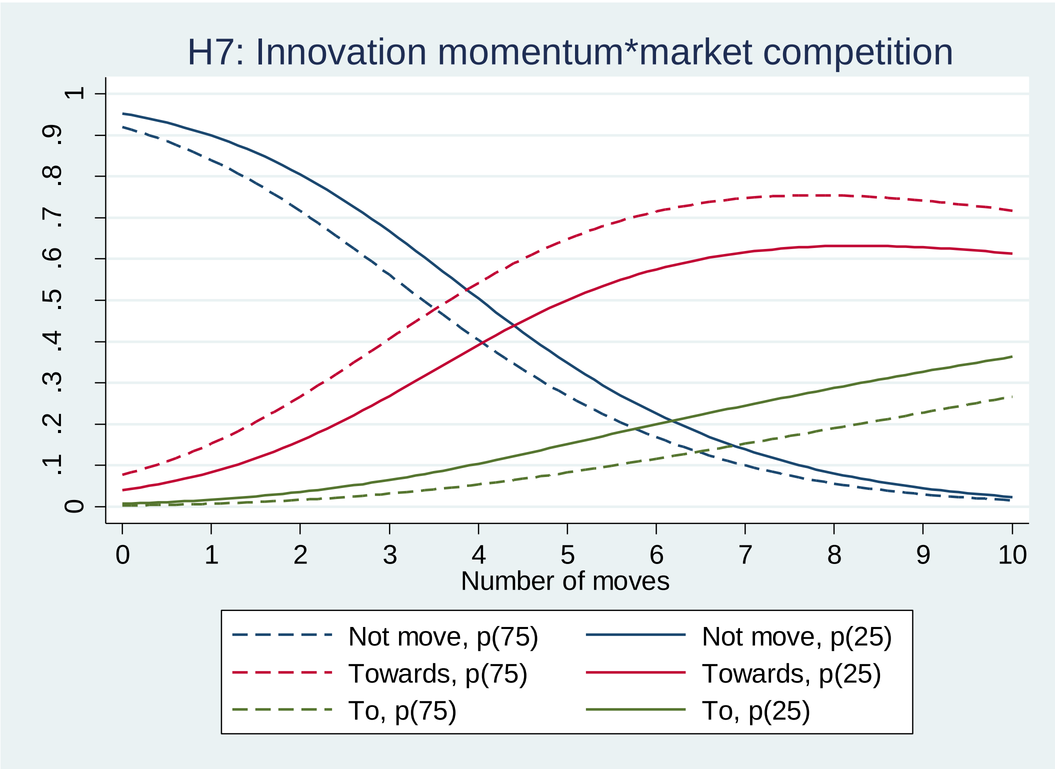
| | | Base: Not move | | Base: Move toward | | Base: Move to | |
|---|---|---|---|---|---|---|---|
| | | **Model 4a** | **Model 4b** | **Model 5a** | **Model 5b** | **Model 6a** | **Model 6b** |
| | | **Move towards** | **Move to** | **Not move** | **Move to** | **Not move** | **Move towards** |
| Interfirm relationships | | -13.45*** | -8.525*** | 13.45*** | 4.926*** | 8.525*** | -4.926*** |
| | | (-21.54) | (-5.67) | (21.54) | (3.63) | (5.67) | (-3.63) |
| Industry growth | | -0.260 | -2.632 | 0.260 | -2.372 | 2.632 | 2.372 |
| | | (-0.30) | (-0.73) | (0.30) | (-0.65) | (0.73) | (0.65) |
| Firm age | | -0.203*** | -0.791** | 0.203*** | -0.588* | 0.791** | 0.588* |
| | | (-3.65) | (-3.14) | (3.65) | (-2.37) | (3.14) | (2.37) |
| Firm size | | 0.000150 | 0.0000925 | -0.000150 | -0.0000576 | -0.0000925 | 0.0000576 |
| | | (0.65) | (0.28) | (-0.65) | (-0.30) | (-0.28) | (0.30) |
| Technology frontier competition | | 0.133 | -0.242 | -0.133 | -0.375 | 0.242 | 0.375 |
| | | (1.25) | (-0.47) | (-1.25) | (-0.71) | (0.47) | (0.71) |
| Patent stock | | 0.0000455 | -0.000166 | -0.0000455 | -0.000212 | 0.000166 | 0.000212 |
| | | (0.62) | (-0.93) | (-0.62) | (-1.19) | (0.93) | (1.19) |
| Recent move | | -0.0644 | 0.446+ | 0.0644 | 0.510+ | -0.446+ | -0.510+ |
| | | (-1.13) | (1.74) | (1.13) | (1.94) | (-1.74) | (-1.94) |
| Current generation | | -0.387+ | -1.109* | 0.387+ | -0.722+ | 1.109* | 0.722+ |
| | | (-1.70) | (-2.47) | (1.70) | (-1.65) | (2.47) | (1.65) |
| Number of plants | | 0.153+ | 0.482** | -0.153+ | 0.329* | -0.482** | -0.329* |
| | | (1.88) | (2.81) | (-1.88) | (2.22) | (-2.81) | (-2.22) |
| Number of generations moved | | -1.622*** | -0.165 | 1.622*** | 1.456+ | 0.165 | -1.456+ |
| | | (-3.72) | (-0.21) | (3.72) | (1.94) | (0.21) | (-1.94) |
| Distance to the technology frontier | H1 | 0.239+ | -2.753** | -0.239+ | -2.993** | 2.753** | 2.993** |
| | | (1.90) | (-3.11) | (-1.90) | (-3.22) | (3.11) | (3.22) |
| Innovation momentum | H2 | 0.912* | 1.514+ | -0.912* | 0.602 | -1.514+ | -0.602 |
| | | (2.32) | (1.86) | (-2.32) | (0.77) | (-1.86) | (-0.77) |
| Experience at the technology frontier | H3 | 0.000689* | 0.00181* | -0.000689* | 0.00112 | -0.00181* | -0.00112 |
| | | (2.46) | (2.42) | (-2.46) | (1.39) | (-2.42) | (-1.39) |
| Prior window of competitive response | H4 | -0.00348* | 0.000169 | 0.00348* | 0.00365 | -0.000169 | -0.00365 |
| | | (-1.97) | (0.02) | (1.97) | (0.47) | (-0.02) | (-0.47) |
| Market competition in the current market | H4 | 0.0149+ | -0.0175 | -0.0149+ | -0.0324* | 0.0175 | 0.0324* |
| | | (1.61) | (-1.52) | (-1.61) | (-2.41) | (1.52) | (2.41) |
| Market share | H6 | 16.46 | 22.37 | -16.46 | 5.913 | -22.37 | -5.913 |
| | | (1.23) | (1.52) | (-1.23) | (0.74) | (-1.52) | (-0.74) |
| Innovation momentum * market competition | H7 | -0.00605+ | -0.00492 | 0.00605+ | 0.00113 | 0.00492 | -0.00113 |
| | | (-1.73) | (-0.87) | (1.73) | (0.20) | (0.87) | (-0.20) |
| Constant | | -3.069*** | 2.600 | 3.069*** | 5.670* | -2.600 | -5.670* |
| | | (-3.40) | (1.13) | (3.40) | (2.14) | (-1.13) | (-2.14) |
| Observations | | 536 | 536 | 536 | 536 | 536 | 536 |
| Pseudo $R^2$ | | 0.2775 | 0.2775 | 0.2775 | 0.2775 | 0.2775 | 0.2775 |

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

Hypothesis $7_{\text{move to or towards}}$ proposes that, the effect of market competition on a technological laggard's decision to move to a new position is likely to be stronger when a laggard innovation momentum is high. In order to test $H7_{\text{move to or towards}}$, I add an interactive term (innovation momentum*market competition) to the simple model. Table 9 shows Model 4-6, the complete model for hypothesis testing.

Contrary to the hypothesis, the coefficient of *innovation momentum* market competition* in Model 4a is negative and statistically significant, suggesting that market competition negatively moderates the relationship between innovation momentum and a technological laggard's decision to move to a new position. Yet, the model estimation by Model 4 shows a trend that supports $H7_{\text{move to or towards}}$. In order to reconcile the conflicts, I first provide graphical evidence that corroborates $H7_{\text{move to or towards}}$, and then explain why the coefficient for the interactive term turns negative.

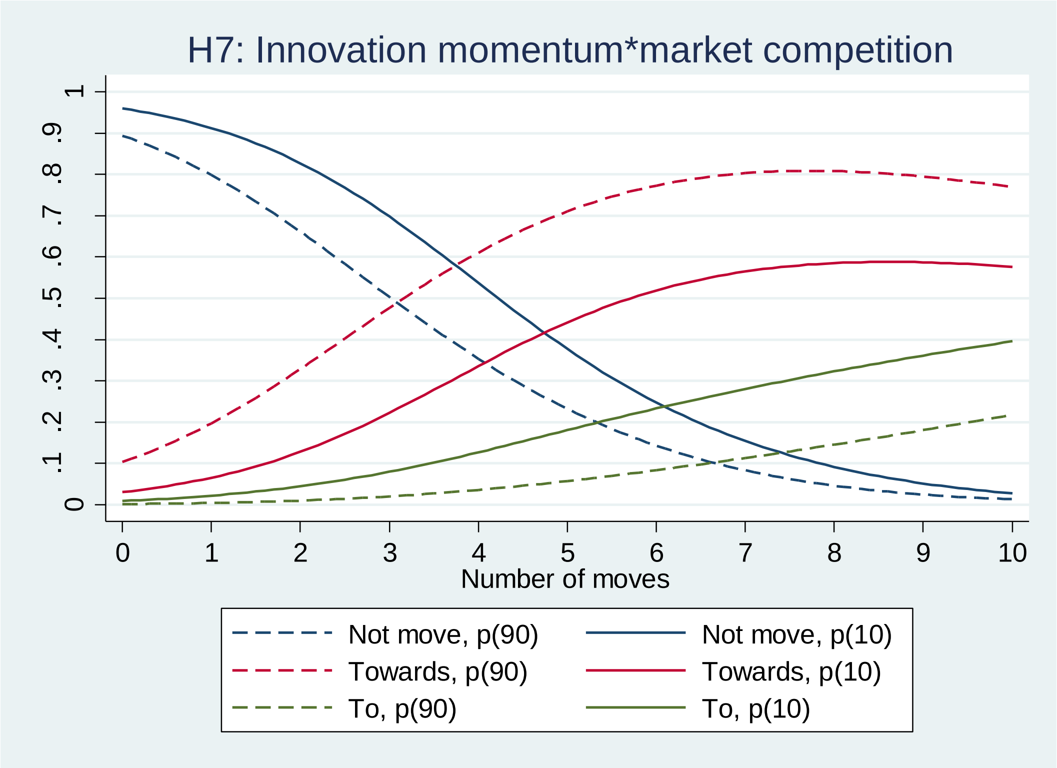
**Figure 16. Model prediction for Hypothesis 7.**




Note:
p(75): technological laggards' market competition is above $75_{th}$ percentile; p(25): technological laggards' market competition is below $25_{th}$ percentile

In Figure 16, a technological laggard experiencing higher market competition (above $75_{th}$ percentile) has a lower probability of not moving from its current position. This finding is in line with competition literature and $H5_{move\ towards\ or\ to}$. In examining the probability of moving towards the technology frontier, when market competition is at a high level, a laggard with higher innovation momentum has a higher probability of moving towards the technology frontier. This observation indeed corroborates $H7_{move\ to\ or\ towards}$.

**Figure 17. Model prediction for Hypothesis 7.**




Note:
p(90): technological laggards' market competition is above $90_{th}$ percentile; p(10): technological laggards' market competition is below $10_{th}$ percentile

Figure 17 reports the estimated probability with a more extreme definition of high and low market competition. The difference in probability further widens for all three strategic alternatives, suggesting a positive effect of market competition on the relationship between innovation momentum and a technological laggard's likelihood of moving to a new position. This finding again corroborates $H7_{\text{move to or towards}}$.

**Table 10. Estimated probability comparison.**

| | | Innovation momentum | | |
|---|---|---|---|---|
| | Market competition | =1 | =5 | =10 |
| Probability of moving towards | p(75) | 0.0776 | 0.648 | 0.7176 |
| | p(25) | 0.04 | 0.5 | 0.613 |
| Probability difference | **p(75)-p(25)** | **0.0376** | **0.148** | **0.1046** |
| Probability of moving towards | p(90) | 0.1042 | 0.7105 | 0.7693 |
| | p(10) | 0.0308 | 0.4414 | 0.5764 |
| Probability difference | **p(90)-p(10)** | **0.0734** | **0.2691** | **0.1929** |

Table 10 summarizes part of estimated probabilities from Model 4. Table 10 brings to our attention at least two importance pieces of information in terms of examining the hypothesis testing results. First, when innovation momentum increases from 1 to 5, the probability increase for p(90) is 0.61 (=0.7105-0.1042) and for p(75) is 0.57 (=0.648-0.0776); both of them increase more than 0.46 of p(25) and 0.41 of p(10). Again, a higher level of market competition further enhances innovation momentum's effect on increasing a technological laggard's probability of moving towards the technology frontier. Second, in an attempt to explain why the interactive term has a negative coefficient, I point out that the value of coefficient is very low (-0.00605), suggesting the negative effect may not produce a noticeable effect until innovation momentum reaches a high value. In Table 10, when innovation momentum increases from 5 to 10, the difference in probability between high and low market competition (p(75) and p(25)) decrease by 0.0434 (=0.148-0.1046). The same change also occur in another group where I define higher competition as p(90) and low competition as p(10). The difference in probability decreases by even more-- 0.0762 (0.2691-0.1929). Hence, the consistent pattern is that, despite a high level of market competition, the innovation momentum's effect on a laggard's probability of moving towards the technology frontier gradually weakens.

The empirical proxy for innovation momentum is the number of moves that a technological laggard has performed since its entry. In explaining why a technological laggard with high innovation momentum slows down as it moves towards the technology frontier, I need to highlight the limit of the dataset. In the flat panel display industry, the average move is usually 0.5 or 1 generation. The current maximum generation in the dataset is 8.5. So, after moving up its plant generation for 8 or 9 times, a laggard probably already runs out of positions that are behind the technology frontier, unless it leapfrogs the technological leader. $H1_{move\ to}$ and $H3_{move}$ has discussed part of the market and technological difference between moving towards and to the technology frontier, and why it is difficult.

Findings from Model 4 can also help to explain why $H5_{move\ towards\ or\ to}$ fails to receive the statistical support. The finding from Model 1 (simple model) suggests that market competition has no effect on a technological laggard's probability of moving to a new position. A closer look at Model 4 (complete model) suggests that market competition is more likely to trigger the move if a technological laggard has higher innovation momentum. That is, the capabilities of moving to a new position is likely to be critical in a laggard's technology deployment decision. This finding furhter underscores the importance of organizational capabilities in the competitive dynamics literature.

### 5.5 Robustness Check

To ensure model robustness, I perform five checks. The first two checks involve using different variable operationalizations. First, the competitive dyanmics literature suggests that an aggressive firm is likely to demonstrate high innovation momentum (Ferrier, 2001). A special feature in the flat panel display industry is that makers rarely close their older plants after a new plant is built. Following the empirical measure of aggressiveness, the proxy for innovation momentum is the generation difference between a technological laggard's most and least advanced plants (Ferrier, 2001; Ndofor *et al*., 2011). The proxy is mean-centering. The model using this new proxy for innovation momentum reports the same results as simple models (Model 1-3). Second, an alternative to approximating market competition is Herfindhal index (Cool & Dierickx, 1993; Derfus *et al*., 2008). Hence the market competition is equal to the sum of squared market share in a given year, given technology. The model using Herfindhal index reports the same results as simple models (Model 1-3).

The next two checks use diffrent statistical models. First, I use multinomial probit model, and the findings from multinomial probit and logit model are consistent with each other. The consistenance also supports the use of multinomial logit model even when the data structure fails to uphold the IIA assumption. Second, the dataset for prior hypothesis testing is limited to only technological laggards. In addressing the concern regarding sample selection, I employ two-stage models. The first regression model is a probit model that I use to test whether a firm is a technological leader or laggard, and retrive the inverse Mills ratio. I then add the inverse Mills ratio as a control variable to the second model, which is a multinominal logit model with a 3-category dependent variable (Heckman, 1979; Shipilov & Li, 2008; Yang, Lin & Lin, 2010). This two-stage model reports the same results as simple models (Model 1-3).

The last check uses the same multinominal logit model (Model 1-3), and limites the sample to technological laggards using the OLED technology. Due to a low number of technological laggards that actually move to the technology frontier (n=3), the model that compares moving to the technology frontier with other two strategic alternatives fails to converge. Yet, the model that compares not moving from the current position with moving towards the technology frontier still produces the same results as the simple models (Model 1-3).

# CHAPTER 6

# POST HOC ANALYSIS

## 6.1 Breakdown of the Market Share: Segment Share

The findings from Model 1 are opposite of the Hypothesis $6_{\text{move to}}$'s prediction that a technological laggard with a greater market share is less likely to move to the technology frontier. An alternative view suggests that a large market share may increase return on innovation, encouraging a laggard to move to the technology frontier (Adner & Zemsky, 2005; Blundell *et al.*, 1999; Demsetz, 1973; Mas-Ruiz & Ruiz-Moreno, 2011; Szymanski *et al.*, 1993). The prior variable operationalization of market share assumes that production value is the same across the board for different sizes of display panel. Because return on innovation may vary with panel sizes, it is of theoretical interest to understand how segment share[34] associates with a laggard's technology deployment decision (Moore, 1991).

I obtain a dataset that contains shipment value and/or volume information and break down into segments. This sub-dataset contains shipment value and/or volume for different panel sizes, ranging from 0.3-inch to 60-inch. The observations period cover 1997 to 2007. I categorize display panels into segments based on their sizes. The large display segment has display panels whose sizes are above 90 percentile of the sample's panel sizes; the small display segment has display panels whose sizes are below 10 percentile of the sample's panel sizes in a given year, given technology.

Following the segment share definition by Cool & Dierickx (1993), I operationalize a technological laggard's segment share-- its shipment value (or volume) in the segment as a

[34] Different from market share, which is a sum of a firm's shipment value proportion to the entire market, a segment share specifically refers to the proportion a firm's shipment value of a given market segment.

proportion of the industry's total shipment value (or volume) in the segment $j$ in a given year, given technology (Cool & Dierickx, 1993). The variable is *segment share*[35].

$$a\ technological\ laggard\ i's\ \ segment\ j\ share = \frac{shipmant_{ij}}{\sum_{n}^{i=1} shipment_{ij}}, i = 1{:}\,n, j = 1{:}\,J$$

In Table 11, Models 7-9 include segment share variables in addition to the original variables from Model 1 (simple model). The discussion focuses on interpreting results from Models 7-9.

[35] Cook and Dierickx (1993) also propose the measure of *segment weight* as the proportion of its shipment value (or volume) in the segment $j$ as a percentage of the total panel shipment value (or volume).

$$a\ technological\ laggard\ i's\ segment\ j\ weight = \frac{shipment_{ij}}{\sum_{m}^{j=1} shipment_{ij}}$$

$$i = 1{:}\,n, j = 1{:}\,J$$

The major difference between segment share and segment weight is the focus of comparing target. The variable segment share represents a technological laggard's external focus on market competition, examining its market position in relation to the industry as a whole; whereas the variable segment weight represents a technological laggard's internal focus on its product portfolio. I adopt the measure of segment share because this study has its focus set on external competition.

**Table 11. Multinomial logistic results** (LCD technology only)

| | | Base: Not move | | Base: Move toward | | Base: Move to | |
|---|---|---|---|---|---|---|---|
| | | **Model 7a** | **Model 7b** | **Model 8a** | **Model 8b** | **Model 9a** | **Model 9b** |
| | | **Move towards** | **Move to** | **Not move** | **Move to** | **Not move** | **Move towards** |
| Interfirm relationships | | -25.08*** | 696.5*** | 25.08*** | 721.6*** | -696.5*** | -721.6*** |
| | | (-26.62) | (25.11) | (26.62) | (26.16) | (-25.11) | (-26.16) |
| Industry growth | | -0.251 | 19.62** | 0.251 | 19.87** | -19.62** | -19.87** |
| | | (-0.13) | (2.73) | (0.13) | (2.83) | (-2.73) | (-2.83) |
| Firm age | | -0.388+ | -54.18*** | 0.388+ | -53.79*** | 54.18*** | 53.79*** |
| | | (-1.86) | (-40.64) | (1.86) | (-41.28) | (40.64) | (41.28) |
| Firm size | | 0.000219 | 0.0685*** | -0.000219 | 0.0683*** | -0.0685*** | -0.0683*** |
| | | (1.50) | (46.86) | (-1.50) | (47.01) | (-46.86) | (-47.01) |
| Technology frontier competition | | 0.103 | -34.01*** | -0.103 | -34.12*** | 34.01*** | 34.12*** |
| | | (0.54) | (-32.20) | (-0.54) | (-30.96) | (32.20) | (30.96) |
| Patent stock | | 0.000000603 | -0.104*** | -0.000000603 | -0.104*** | 0.104*** | 0.104*** |
| | | (0.00) | (-28.38) | (-0.00) | (-28.43) | (28.38) | (28.43) |
| Recent move | | 0.215 | 97.09*** | -0.215 | 96.88*** | -97.09*** | -96.88*** |
| | | (1.11) | (31.26) | (-1.11) | (31.48) | (-31.26) | (-31.48) |
| Current generation | | -0.477 | -284.1*** | 0.477 | -283.6*** | 284.1*** | 283.6*** |
| | | (-1.27) | (-47.86) | (1.27) | (-48.21) | (47.86) | (48.21) |
| Number of plants | | 0.322*** | 85.73*** | -0.322*** | 85.41*** | -85.73*** | -85.41*** |
| | | (3.97) | (47.53) | (-3.97) | (48.05) | (-47.53) | (-48.05) |
| Number of generations moved | | -1.874** | -19.65*** | 1.874** | -17.78*** | 19.65*** | 17.78*** |
| | | (-3.08) | (-9.45) | (3.08) | (-7.92) | (9.45) | (7.92) |
| Distance to the technology frontier | H1 | 0.321 | -464.6*** | -0.321 | -464.9*** | 464.6*** | 464.9*** |
| | | (1.55) | (-43.91) | (-1.55) | (-43.84) | (43.91) | (43.84) |
| Innovation momentum | H2 | 0.432 | 144.1*** | -0.432 | 143.7*** | -144.1*** | -143.7*** |
| | | (1.08) | (25.48) | (-1.08) | (26.09) | (-25.48) | (-26.09) |
| Experience at the technology frontier | H3 | 0.00128* | 0.213*** | -0.00128* | 0.212*** | -0.213*** | -0.212*** |
| | | (2.54) | (25.83) | (-2.54) | (26.06) | (-25.83) | (-26.06) |
| Prior window of competitive response | H4 | -0.00108 | 0.201*** | 0.00108 | 0.203*** | -0.201*** | -0.203*** |
| | | (-0.34) | (24.71) | (0.34) | (22.76) | (-24.71) | (-22.76) |
| Market competition in the current market | H4 | -0.0117 | -6.128*** | 0.0117 | -6.116*** | 6.128*** | 6.116*** |
| | | (-1.52) | (-35.44) | (1.52) | (-35.81) | (35.44) | (35.81) |
| Market share | H6 | 2.313 | -1928.8*** | -2.313 | -1931.1*** | 1928.8*** | 1931.1*** |
| | | (0.25) | (-38.80) | (-0.25) | (-38.86) | (38.80) | (38.86) |
| Segment share (large panels) | | 0.702 | 146.7*** | -0.702 | 146.0*** | -146.7*** | -146.0*** |
| | | (0.40) | (9.69) | (-0.40) | (9.39) | (-9.69) | (-9.39) |
| Segment share (small panels) | | -4.468+ | -797.4*** | 4.468+ | -792.9*** | 797.4*** | 792.9*** |
| | | (-1.80) | (-46.26) | (1.80) | (-45.78) | (46.26) | (45.78) |

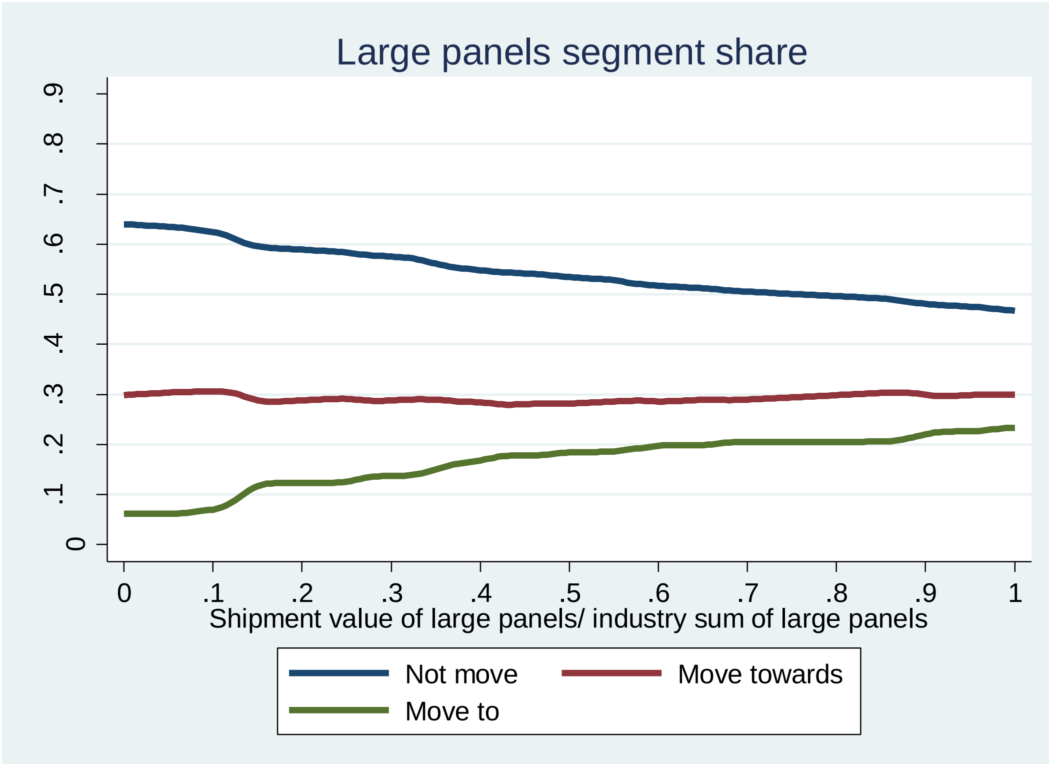
**Table 11 (cont.)**

| | Base: Not move | | Base: Move toward | | Base: Move to | |
|---|---|---|---|---|---|---|
| | **Model 7a** | **Model 7b** | **Model 8a** | **Model 8b** | **Model 9a** | **Model 9b** |
| | **Move towards** | **Move to** | **Not move** | **Move to** | **Not move** | **Move towards** |
| Constant | -0.369 | 1179.9*** | 0.369 | 1180.3*** | -1179.9*** | -1180.3*** |
| | (-0.21) | (50.41) | (0.21) | (50.45) | (-50.41) | (-50.45) |
| Observations | 146 | 146 | 146 | 146 | 146 | 146 |
| Pseudo $R^2$ | 0.5118 | 0.5118 | 0.5118 | 0.5118 | 0.5118 | 0.5118 |

*z* statistics in parentheses

$^{+}$ $p < 0.1$, $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

**Figure 18. Model estimation by Model 9, large panel segment.**




In Model 9, the coefficients of variable *segment share (large panels)* are negatively significant. Figure 18 reports the model estimation by Model 9. In Model 9, a technological laggard with a greater share in large panel segment has a higher probability of moving to the technology frontier as opposed to moving towards or not moving from its current position.

It is worth noting that a technological laggard does have economic incentives to increase its share in large panel segment. Moore (1991) proposes that products reputation in the high end segment often carry itself over to other lower end segments. Because a product in the high end segment is often perceived as having superior technology, a firm's strong presence in the high end segment usually has a positive impact on how customers perceive might view the technological competitiveness of its products in others segments. Additionally, a high share often signals superior product quality (Caminal & Vives; 1996; Hellofs & Jacobson, 1999). Once a segment share exceeds a certain threshold, additional shares may serve to perpetuate the perception that it is of superior quality, which is likely to attract more sales. In sum, a technological laggard has economic incentives to expand its share in large panel segment.

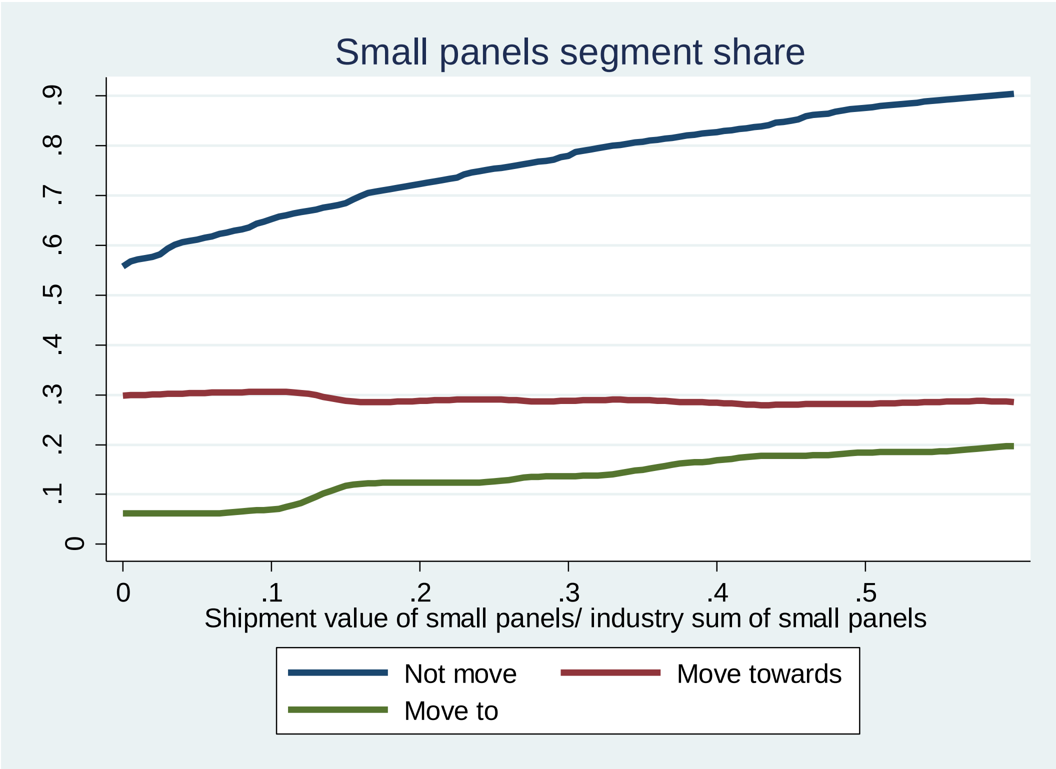
**Table 12[36]. Plant generations and sizes of panel produced.**

| Generation | G5 | | | | G5.5 | G6 | | G7 | G7.5 | G8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Size (mmxmm) | 1100x 1200 | 1100x 1250 | 1100x 1300 | 1200x 1300 | 1300x 1500 | 1500x 1800 | 1500x 1850 | 1870x 2200 | 1950x 2250 | 2160x 2400 |
| 17 | 9 | 12 | 12 | 12 | 16 | 24 | 25 | 36 | 36 | -- |
| 17W | 12 | 12 | 12 | 15 | 18 | 24 | 25 | 35 | 35 | -- |
| 19 | 9 | 9 | 9 | 12 | 12 | 16 | 16 | 25 | 25 | -- |
| 20.1 | 6 | 6 | 9 | 9 | 12 | 16 | 18 | 25 | 25 | -- |
| 23W | 6 | 6 | 8 | 8 | 8 | 12 | 12 | 21 | 24 | 32 |
| 26W | 4 | 6 | 6 | 6 | 8 | 12 | 12 | 18 | 18 | 18 |
| 30W | 3 | 3 | 3 | 3 | 6 | 8 | 8 | 12 | 12 | 15 |
| 32W | 2 | 2 | 3 | 3 | 4 | 8 | 8 | 12 | 12 | 15 |
| 37W | 2 | 2 | 2 | 2 | 2 | 6 | 6 | 8 | 8 | 8 |
| 40W | 2 | 2 | 2 | 2 | 2 | 3 | 4 | 8 | 8 | 8 |
| 42W | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 6 | 8 | 8 |
| 46W | 1 | 2 | 2 | 2 | 2 | 3 | 3 | 6 | 6 | 8 |
| 54W | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 6 |
| 57W | | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 |
| 65W | | | | | 1 | 2 | 2 | 2 | 2 | 3 |

Producing a larger display panel is one of the keys in driving a technological laggard to move to the technology frontier. In Table 12, a higher generation plant can produce larger display panels. Some very large panels can only be produced in the most advanced generation plant. The findings from Model 7 support this observation. A technological laggard with higher share in large panel segment is more likely to build the most advanced generation plant because doing so enables it to produce larger display panels.

[36] Global Market and Technical Development of Flat Panel Display 2006, Photonics Industry & Technology Development Association, Taiwan, p.2-2, Table 2-1-1.

**Figure 19. Model estimation by Model 7, small panel segment.**




In Model 9, the coefficients of variable *segment share (small panels)* are positively significant. The findings from Model 9 suggest that a technological laggard with a greater share in small panel segment has a lower probability of moving to the technology frontier as opposed to moving towards the technology frontier or not moving from its current position. Furthermore, in Model 7, the coefficients of variable *segment share (small panels)* are negatively significant. The findings from Model 7 suggest that a technological laggard with greater share in small panel segment has a higher probability of not moving from its current position than other alternative moves. Figure 19 summarizes the estimation made by Model 7. A technological laggard's probability of not moving from its current position increases with its share in small panel segment.

Although in Table 12 a higher generation plant can produce small panels at greater quantity, enabling a technological laggard to achieve economies of scale, findings in Model 9 do not support this economic reasoning. I still maintain the view that the anticipated economic payoff may be the explanation. As display panels are usually homogenous products regardless of makers, the makers typically have difficulty in increasing the economic payoff through direct markup in the market. The actual economic payoff is likely to come from cost savings from production.

**Table 13[37]. The substrate area utility by plant generation.**

| Generation[38] | | G3 | G3.5 | G3.7 | G4 | |
|---|---|---|---|---|---|---|
| Substrate size ($mm^2$) | | 550x670 | 600x720 | 670x850 | 750x950 | 900x1100 |
| Productivity | Initial substrate input (1000 units/ month) | 35 | 30 | 25 | 20 | 15 |
| | Cut panels (15", 18", 21") | 4, 2, 1 | 4, 2, 2 | 6, 4, 2 | 6, 4, 4 | 9, 6, 6 |
| | 15" panels production volume (1000 units/ month) | 126 | 108 | **135** | 108 | **121** |
| | Yield (%) | 90 | 90 | 90 | 90 | 90 |
| | Production volume | 1 | 1-1.2 | 1-1.2 | 1-1.3 | 1-1.5 |
| Equipment costs | | 1 | 1.2 | 1.3 | 1.4 | 1.6 |
| Investment/ costs | 15" | 1 | **0.7** | 1 | 0.8 | 0.9 |
| | 18" | 1 | 0.7 | 1.5 | 1.2 | 1.4 |
| Area | Equipment designed area | 1 | 1.4 | 1.4 | 1.5 | 2 |
| | Area utilization efficiency (15") | 1 | **1.4** | 0.9 | 1 | 0.9 |

Table 13 suggests that, when producing small panels (e.g., 15"), a lower generation plant may have better productivity. A Gen 3.7 plant can yield more 15" display panels than a Gen 4 plant[39]. Also, a Gen 3.5 plant has the best area utilization efficiency and the lowest investment/cost ratio than higher generation plants. Biing-Seng Wu, Chi Mei Optoelectronics' executive vice president, explains CMO's focus on product mix that enables CMO's each plant to produce efficiently:

[37] Tian, M. 2008. Flat Panel Display 1999, Cheng-Jin Culture, p.36, Table 6, Taipei, Taiwan

[38] Generation information is supplied by Technical Development of Flat Panel Displays, p.26, Table 10-1, Wunan Book Co., Ltd, Taiwan, 2008

[39] The same productivity advantage also occurs at higher generation plants. In Harvard Business case Chi Mei Optoelectronics, "[a] Gen 5 fab could produce eight 22-inch-wide monitors simultaneously, but a Gen 5.5 could produce 12 at a relatively small increase in capital cost. That translated into a huge cost advantage," p. 11.

> "[W]e think about how we will cut it in order to minimize the glass wastage and produce the product that people want. That is actually the main focus of our decision on which generation to build," Shih, Shih, Wang & Yu (2010: 11)

In addition to the economic reason, the competition within each strategic group provides a further explanation as to why a great share in small panel segment discourages a technological laggard from moving to the technology frontier, and a great share in large panel segment encourages a technological laggard to move to the technology frontier.

The market segmentation, due to distinct product applications, is likely to divide technological laggards into different strategic groups based on the demand features, e.g., panel size (Bergen & Peteraf, 2002; Clark & Montgomery, 1999). Hence, not all technological laggards expect to face the same characteristics of market competition; managers tend to identify rival firms producing similar products and associate those rival firms into their strategic group (Bergen & Peteraf, 2002; Clark & Montgomery, 1999; Porac & Thomas, 1990).

Clark and Montgomery (1999) posit that firms tend to imitate actions by successful firms. Hence, for a technological laggard with a great share in large panel segment is more inclined to identify the technological leader who produces large panels and follows the leader's technology deployment decision. Because firms in the same strategic group tend to react in the same way toward external threats (Fiegenbaum & Thomas, 1995; Smith *et al.*, 1997), a laggard producing more large panels is likely to choose the same technology deployment decision as the technological leader, who usually prioritizes its initiatives with the intent to maintain its technological lead.

Although the pattern of competition is usually similar within strategic group, the acutal actions taken between strategic groups are usually different (Mas-Ruiz & Ruiz-Moreno, 2011). A technological laggard with a great share in small panel segment is more likely to form its strategic group with other technological laggards who mainly manufacture small panels (Porac & Thomas, 1990). Different strategic groups usually have different target performance levels (Fiegenbaum, Hart & Schendel, 1996; Fiegenbaum & Thomas, 1990). Based on information provided by industry reports, a laggard producing small panels tends to emphasize profitability. As such, a laggard in the strategic group of small panels is more likely to set its goal to improve manufacturing process to achieve better production yield than, say, to pursue the technological leadership.

It is worth noting that findings from a model that incorporates segment shares can help to resolve the debate over whether a market share encourages more innovations. When a technological laggard has a high share in a segment that is prone to innovate, it usually chooses to deploy the more advanced technology that directly responds to the demand characteristics in the segment. Conversely, if the segment where a laggard has a high share is less innovation driven, the exhibition of inertia is likely to be more prominent regarding its decision of deploying the more advanced technology.

### 6.2 Dual Technological Trajectories

So far this study has assumed that there is only one technological trajectory (LCD technology only). This assumption nevertheless leads to a cylindrical view (Dosi, 1982). In the flat panel display industry, the OLED technology is considered to be the next dominant technology after the LCD technology. The current technological laggards using the LCD technology have evolved a different behavior in response to the rise of the OLED technology. At here, I highlight two characteristics of LCD and OLED technologies to facilitate the following post-hoc analysis. First, a display panel produced using the LCD or the OLED technology may vary in some technical aspects, but product applications are greatly overlapped. Hence, in most cases the market demand for display panels varies marginally with the type of technology used. Second, the relationship between the LCD and OLED technologies is more of complementary one than a substitute one.

**Table 14. Technological leaders and laggards' firm-year observations by technology.**

| | | LCD | | |
|---|---|---|---|---|
| | | Laggard | Leader | Total |
| OLED | No Entry | 648 | 145 | 793 |
| | Entry | 32 | 1[40] | 33 |
| | Total | 680 | 146 | 826 |

This part of post-hoc analysis focuses on LCD technological laggards who also produce display panels using the OLED technology. Table 14 presents data outlook. Only 32 LCD technological laggards produce OLED display panels. Despite a small number of observations, the phenomenon of a firm, especially a technologically lagging firm, producing products using technologies from different technological trajectories lacks theoretical explanations (Christensen, 1997). Further, most research literature has assumed that one technological trajectory replaces another sooner or later (Adner & Zemsky, 2005; Christensen & Rosenbloom, 1995); whereas the LCD and OLED technologies are two technological trajectories complementary to each other regarding their technical features and product applications.

The OLED is a relatively nascent technology in the flat panel display industry. With the first mass production by Pioneer takes place in 1997[41], the production of display panels using the OLED technology gradually does not take off until 2004. The observation period for the dataset

[40] Although there is only one LCD technological leader using the OLED technology in the same year during the observation period, there are sister firms or firms in alliance with the technological leaders in the LCD and OLED technologies. They are Samsung Electronics & Samsung SDI in 2005, and 2008, and S-LCD & Samsung SDI in 2006. S-LCD is the joint venture by Sony and Samsung Electronics.

[41] OLEDs: The History and Future Trends, Mike Hack, Universal Display Corporation. Source: apps1.eere.energy.gov/buildings/publications/pdfs/ssl/hack.pdf

(year 1997 to 2007) partially covers this mass production period, which allows me to study the competitive dynamics of the OLED technology at its early stage.

In examining the likelihood of an LCD technological laggard producing display panels using the OLED technology, I define a binomial dependent variable as 1 if an LCD technological laggard produces display panels using the OLED technology in a given year, and 0 if it does not. Models 10-11 maintain the same independent and control variables from Model 1 (simple model). In the following I highlight the major findings from the models. Models 10-11 are random-effect logistic models. Furthermore, survival analysis can be a suitable model in analyzing a technological laggard's decision to enter the OLED technological trajectory. To ensure model robustness, I choose to let Models 12-13 be Cox proportional hazards model with the same independent and control variables from Models 10-11.

**Table 15. Random-effect logistic model & Cox proportional hazards model;** Dependent variable is 1 when a technological laggard's enters OLED, and is 0 when not; hazard is the entry of OLED technological trajectory.

| | | Random-effect logistic | | Cox proportional hazard | |
|---|---|---|---|---|---|
| | | **Model 10** | **Model 11** | **Model 12** | **Model 13** |
| Interfirm relationships | | 2.893 | 2.895 | 35.938 | 23.543 |
| | | (0.92) | (0.75) | (1.45) | (1.32) |
| Industry growth | | 7.968* | 7.159* | 1541.942* | 943.546* |
| | | (2.35) | (2.14) | (2.25) | (2.10) |
| Firm age | | -0.0447 | -0.0817 | 0.881 | 0.8828 |
| | | (-0.43) | (-0.73) | (-1.27) | (-1.26) |
| Firm size | | 0.000787+ | 0.0000388 | 1.0005 | 1.00008 |
| | | (1.71) | (0.08) | (1.04) | (0.15) |
| Technology frontier competition | | -1.720** | -1.656** | 0.5297 | 0.6351 |
| | | (-2.73) | (-2.59) | (-1.12) | (-0.79) |
| Patent stock | | 0.0000877 | 0.00003 | 1.00004 | 1.00003 |
| | | (0.75) | (0.23) | (0.49) | (0.30) |
| Recent move | | 0.0496 | 0.0699 | 0.9618 | 0.9989 |
| | | (0.47) | (0.64) | (-0.42) | (-0.01) |
| Current generation | | 1.363*** | 1.500*** | 2.986** | 4.1994** |
| | | (3.29) | (3.58) | (2.69) | (3.07) |
| Number of plants | | 0.228 | 0.169 | 1.052 | 0.9550 |
| | | (1.56) | (1.09) | (0.43) | (-0.33) |
| Number of generations moved | | -0.521 | -0.359 | 0.6923 | 0.6633 |
| | | (-0.93) | (-0.64) | (-0.79) | (-0.88) |
| Distance to the (LCD) technology frontier | H1 | 0.776* | 0.766* | 2.009* | 1.9645+ |
| | | (2.30) | (2.24) | (2.02) | (1.91) |
| Innovation momentum | H2 | 0.228 | 0.0951 | 0.9114 | 0.8233 |
| | | (0.66) | (0.26) | (-0.29) | (-0.57) |
| Experience at the technology frontier | H3 | 0.0000637 | 0.000301 | 1.0001 | 1.0001 |
| | | (0.12) | (0.53) | (0.26) | (0.22) |
| Prior window of competitive response | H4 | -0.00415 | -0.00449 | 0.9967 | 0.9964 |
| | | (-1.44) | (-1.54) | (-1.28) | (-1.35) |
| Market competition in the current market | H4 | 0.0202+ | 0.0246* | 1.013 | 1.0201+ |
| | | (1.90) | (2.15) | (1.23) | (1.69) |
| Market share | H6 | -61.49+ | -54.74+ | 0.0000 | 0.0000 |
| | | (-1.74) | (-1.71) | (-1.15) | (-1.02) |
| Distance*market share | | | 25.18* | | 14754.6+ |
| | | | (2.37) | | (1.55) |
| Constant | | -11.94*** | -12.15*** | | |
| | | (-3.60) | (-3.71) | | |
| Observations | | 516 | 516 | 516 | 516 |

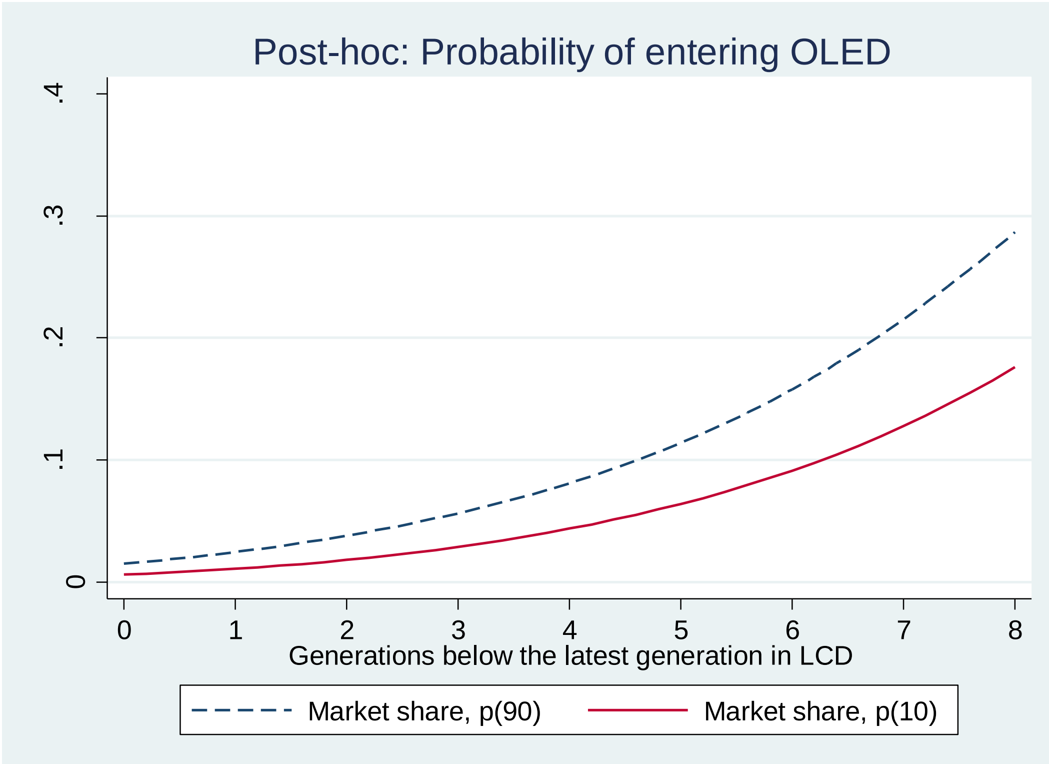
*z* statistics in parentheses. $^{+}$ $p < 0.1$, $^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

In Table 15, Model 10's the variable *distance to the (LCD) technology frontier* is positively significant. Model 10 suggests that a technological laggard that is further behind the technology frontier of LCD is likely to enter the OLED technological trajectory. Model 12 reports the same finding as Model 10. From the perspective of capabilities, technological capabilities that an LCD technological laggard has may be applicable for developing the OLED technology. Hence a technological laggard can use its knowledge in LCD to develop the OLED technology.

The positive and significant coefficient of market competition in Model 11 and 13 lends support to the view that a technological laggard enters the OLED technological trajectory with the intention of seeking a less competitive market. From the perspective of competitive dynamics, products using the OLED technology generally experience lower competition than those using the LCD technology during the observation period. A technological laggard may be more inclined to invest in a less competitive market where return on innovation is likely to be higher (Cool & Dierickx, 1993). Thus, a technological laggard can expect to achieve a better economic payoff by producing products using the OLED technology.

Hypothesis development and post-hoc analysis both maintain that the market share also affects a technological laggard's technology deployment decisions. Hence, in addition to distance to the technology frontier, a market share may also determine an LCD laggard's likelihood of deploying the OLED technology. Model 11 examines the interactive effect of distance and market share on the likelihood of an LCD laggard producing display panels using the OLED technology.

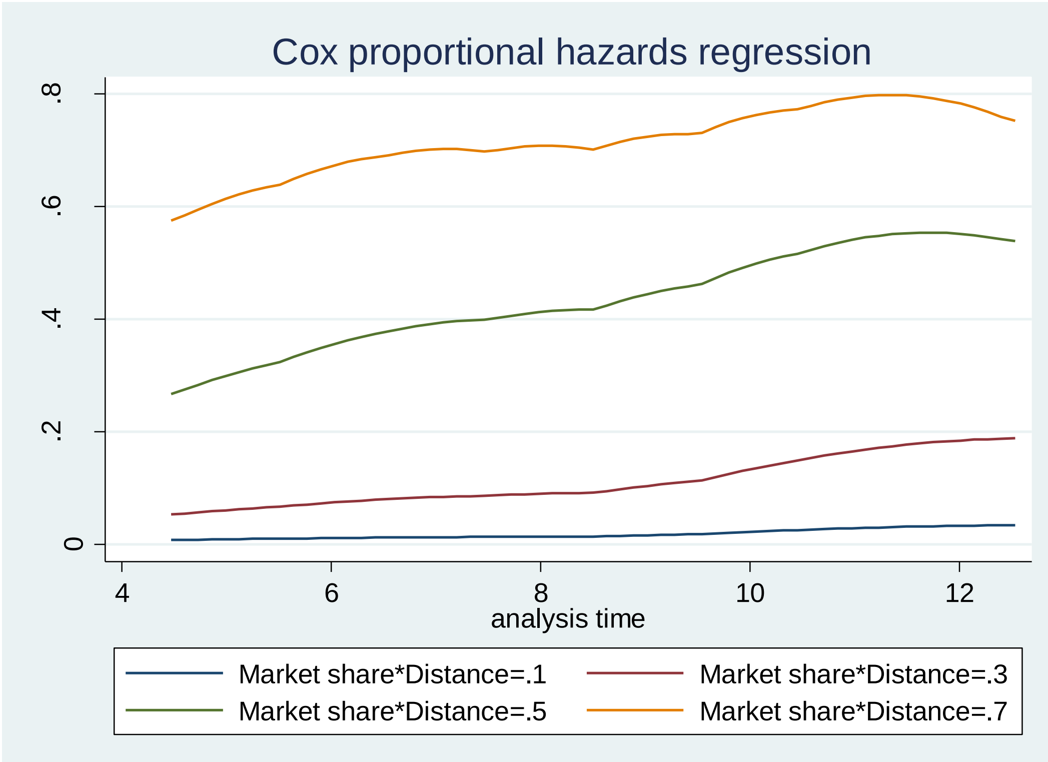
**Figure 20. Model estimation by Model 11.**




Note:
p(90): technological laggards' market share is above $90_{th}$ percentile; p(10): technological laggards' market share is below $10_{th}$ percentile

In Model 11, the variable *distance*market share* is positively significant. The market share enhances the positive effect of distance on a technological laggard's likelihood of entering the OLED technological trajectory. In Figure 20, when a technological laggard has a greater market share in the LCD technological trajectory, the distance to the technology frontier has a stronger positive effect on its likelihood of entering the OLED technological trajectory.

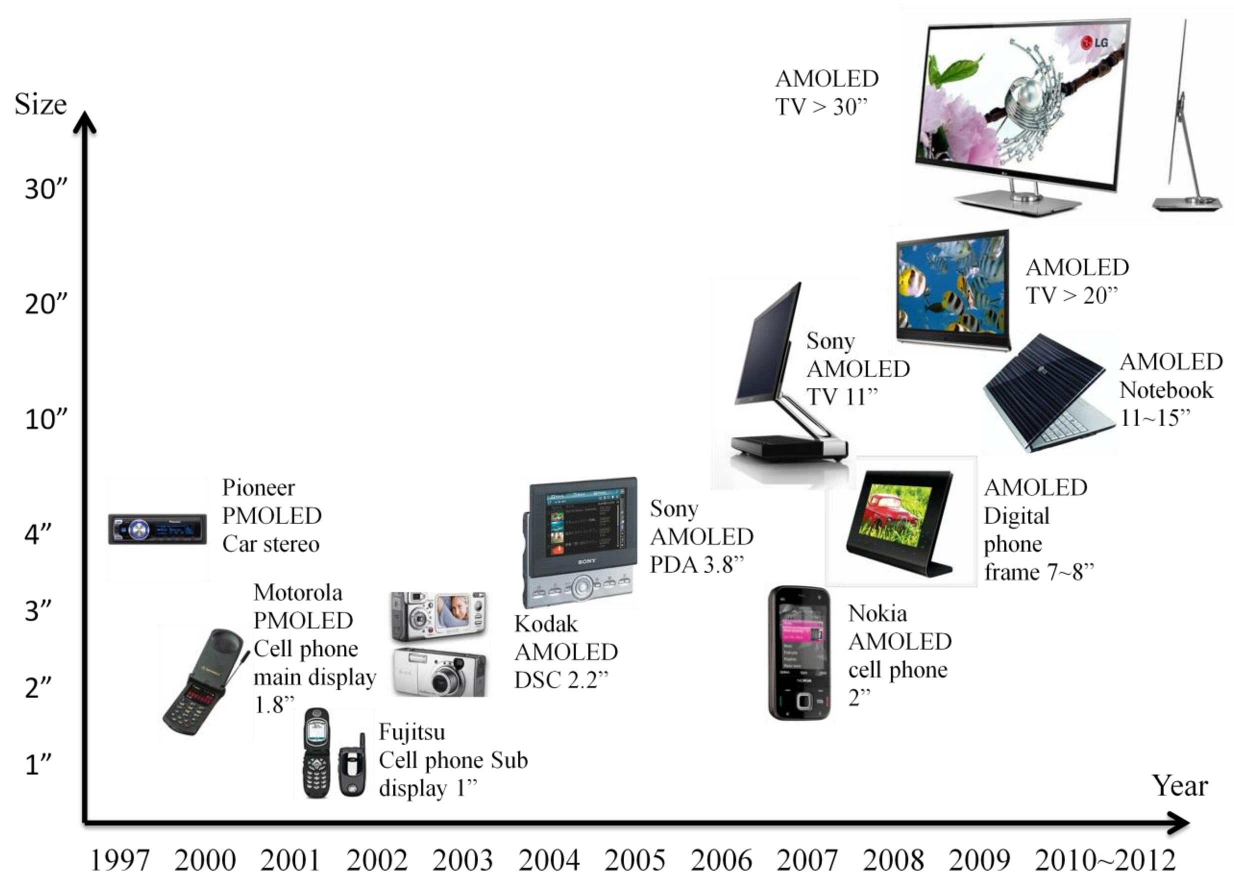
**Figure 21. Survival analysis model estimation by Model 13.**




Model 13 (Cox proportional hazard model) lends further support to Model 11. As shown in Figure 21, a technological laggard is more likely to enter the OLED technological trajectory when its distance and market share are both higher.

As a whole, a technological laggard with a great market share is likely to carry on innovating to maintain its market share; a technological laggard that is further behind the LCD technology frontier usually has difficulty moving to or towards the LCD technology frontier due to capabilities constraints and competitive dynamics. Taken together, if an LCD technological laggard that is further behind the LCD technology frontier plans to maintain or gain more market share, producing display panels using the OLED technology may help it to work around technological difficulties and market competition. Thus, entering the OLED technological trajectory becomes a technological laggard's strategic response to its lagging position in the LCD technological trajectory (Mitchell, 1989). In the following discussions, I incorporate more industry information from the flat panel display industry to further explain an LCD technological laggard's decision to enter the OLED technological trajectory.

**Figure 22[42]. OLED technology and its product applications.**




During the observation period (from 1997 to 2007), the competition among product using the OLED technology has been comparatively lower than the LCD technology due to its newness to the industry. Figure 22 provides a temporal view of the application and size growth of display panel using the OLED technology. Before 2007, the OLED technology is still a technology used almost exclusively in producing panels with size smaller than 11", a size normally considered small by the standard in the LCD technology trajectory. Therefore, an LCD technological laggard with most of its production in small display panels, is usually positioned further behind

[42] Tian, M. 2008. Global Market and Technical Development of Flat Panel Display 2008, Photonics Industry & Technology Development Association, p.4-27, figure 4-2-5, Taiwan

the technology frontier, and is more likely to enter the OLED technological trajectory to capture a piece of the market demand of which it has a high share.

The organizational capabilities view helps explain why an LCD technological laggard attempts to enter the OLED technological trajectory. First, it is possible for a laggard to develop a technology based upon its existing knowledge (Agarwal *et al.*, 2004; Carroll, Bigelow, Seidel & Tsai, 1996; Khessina & Carroll, 2008). For example, a number of flat panel makers are semiconductor makers prior to their entry into the flat panel display industry. The similarity between semiconductor manufacturing and flat panel display manufacturing enables the makers to achieve such technological transition. Likewise, the technical similarity[43] between LCD and OLED enables an LCD technological laggard to develop display panels using the OLED technology, and may even do so at lower costs (Dixit, 1989; Helfat & Eisenhardt, 2004).

Second, an LCD technological laggard's knowledge of rivals and market can be a complementary capability when it enters the OLED technological trajectory. An LCD laggard that is already producing large volume of small panels is likely to be more capable of managing the market competition, because it knows the terms of competition specific to small panel market segment. Additionally, an LCD laggard is likely to encounter the same rivals who produce small panels using the LCD technology. A laggard's prior experience with the same rivals can help it to better manage the market competition (Bergen & Peteraf, 2002). On the flip side, an LCD laggard is likely to sell its OLED display panels to the same firms who are the buyer of its LCD display panels. An LCD laggard may produce products using the OLED technology to strengthen its market position in small panel market segment.

[43] Iwai, Y., 2002, The Key Components, Materials, and Skills of Flat Panel Display, Kogyo Chosakai Publishing Co., Ltd, Japan

Furthermore, a technological laggard generally has economic incentives to increase its sales in small panels as well. The flat panel display industry has undergone volatile industry cycles[44]. The industry sales of medium to large panels often turn sluggish due to the weakened demand in other industries, such as the personal computer industry. Compared with fickle demand for medium and large panels, the demand for small panels has been more stable due to extremely diversified product applications, including watches, mobile devices, game machines (e.g., Pachinko), and so on[45]. The stable and strong market demand can encourage a technological laggard who already commands a high share of small panel segment to adopt other technologies to better capture an even larger piece of the market.

Taken together, a combined view of organizational capabilities and competitive dynamics offers theoretical explanations as to answer why an LCD technological laggard chooses to produce display panels using the OLED technology. A technological laggard is likely to choose to pursue dual (LCD and OLED) technological trajectories to leverage of its existing organizational capabilities, and strengthen its position in key segments of the market.

[44] Zhang, B. 2007. Global TFT LCD Panel and Driver IC outlook, presented at Yokogawa Shanghai Conference, Shanghai, China.

[45] Flat-panel displays: Cracking up, The Economist, Jan 17th 2012.

# CHAPTER 7

# DISCUSSION & CONCLUSION

This dissertation asks the research question: *What determines by how much, if at all, technological laggards advance towards the technology frontier?* This study builds on work in firm capabilities and competitive dynamics to examine a technological laggard’s technology deployment decision. The firm capabilities research, with its inward-looking focus, examines a technological laggard's capabilities to innovate; while the competitive dynamics research, with a focus on external conditions, examines a technological laggard's anticipated economic payoff from innovation. The model in this study combines the firm capabilities and competitive dynamics researches and provides a more complete model that can be helpful in explaining and predicting a technological laggard's innovation behavior (Ndofor *et al.*, 2011).

The empirical testing in the flat panel display industry provides support for the proposed theoretical model. Support for the theoretical model suggests that both organizational capabilities and the anticipated economic payoff jointly determine a technological laggard's decision as to whether to attempt to move to the technology frontier. A laggard is more likely to choose to remain lagging if doing so enables it to better utilize its current organizational capabilities, and if it anticipates a better economic payoff by remaining a technological laggard than by becoming a technological leader. Conversely, the experience at the technology frontier is especially conducive to encouraging a laggard to move to the technology frontier. The experience at the technology frontier not only motivates a laggard to move to the technology frontier, but also enables it to develop organizational capabilities that can help it manage the competition at the technology frontier.

The current study develops a theoretical model that includes internal and external factors. Strong empirical support of firm-level hypotheses (H1-3) and insignificant statistical results from environment-level hypotheses (H4-5) suggest that organizational characteristics may carry a heavier weight on influencing a technological laggard's technology deployment decision, underscoring the role of the focal firm's capability in the competitive dynamics literature. The empirical findings from this dissertation complement the competitive dynamics literature by suggesting that, at the dual presence of organizational capabilities and the competition in the environment, organizational capabilities are more likely to be a dominant factor in determining a firm's competitive behavior with respect to technology deployment.

Due to insignificant statistical results of H4-6, I conduct post-hoc analyses in an effort to complete the theories for laggard strategy. In the analysis of segment share, the formation of strategic group based on product characteristics is rather clear. In essence, a technological laggard that associates itself with the technological leader shows the tendency towards deploying the more advanced technology, and attempts on the technological leadership; whereas a technological laggard in a strategic group in which firms produces products using less advanced technology demonstrates inertia towards innovating. In the analysis of technological trajectory, I infer from the empirical findings that technological lagging behind the technology frontier is a critical factor that leads an LCD technological laggard to pursue dual technological trajectories. Complementarity makes it convenient for a laggard to simultaneously operate with the LCD and OLED technologies. The potential economic payoff from a greater share in a given segment augments economic incentive for a laggard to undertake the technological risk in developing dual technological trajectories.

In summary, the internal factors in the theoretical model can explain and predict a technological laggard's technology deployment decision. The empirical findings underscore the importance of the focal firm's capability how organizational capabilities are conducive to competitive actions. Although external factors do not receive statistical support, post-hoc analysis finds convincing evidence to support external factors' influence on a laggard's technology deployment decision. Segment share is a better proxy than market share when it comes to predicting a laggard's technology deployment decision because it distinguishes a laggard's economic incentives to innovate based on strategic groups. The prediction is corroborated when the analysis considers dual technological trajectories. Thus, to substantiate our understanding of laggard strategy, we need to understand both internal and external factors.

### 7.1 Limitations

This dissertation has several limitations. As is the case in studies that employ data from a single industry, the findings may be limited in terms of its generalizability to other industries that has little in common with the flat panel display industry. Yet, this study is generalizable to industries with similar technical setting, such as the disk-drive industry (Agarwal *et al*., 2004; Christensen, 1997) and the printer industry (de Figueiredo & Teece, 1996). Furthermore, a technological laggard's two strategic actions--*moving to* and *beyond* the technology frontier are combined as one single move, because theories from the firm capabilities and competitive dynamics researches do not distinguish predictions in this regard. A goal for future research may incorporate first mover advantage literature to dissect the firm behavior at the technology frontier and what leads to the advancing of the technology frontier. Moreover, the empirical proxy for market competition is not perfect. Given that the hypothesized prediction is grounded in well-established literature, it is possible that the currently less than perfect proxy for market competition causes statistical insignificance. Future research can adopt a methodological solution that can not only approximate but also distinguish between market and technological competition. This approach will help researchers make progress on technology competition study.

### 7.2 Future Research

Examining a technological laggard's competitive behavior and the technological leader's strategic responses to technological laggard's technology deployment decision through the lens of real options theory is a topic worthwhile undertaking (Trigeorgis, 1996). Conner (1986) suggests that the technological leader uses wait strategies. The technological leader may be better off waiting until a technological laggard attempts to surpass it (Gilbert & Newbery, 1982; Pacheco-de-Almeida, 2010). If a technological laggard does not move to the technology frontier, the introduction of new product may be delayed, or never occurred (Smit & Ankum, 1993). Indeed, a technological leader's technology deployment decision is to an extent influenced by other technological laggards' strategic moves.

On a broader scale, it is worth examining the causality between the degree of supply chain integration and a firm's technology deployment decision. This line of study contributes to technology industries where innovation is often the result of collective acts. Some firms produce invention, and some firms commercialize it[46] (Roberts, 2007). Patent house such as RISC in the mobile computing industry, and CREE and Cambridge Display in flat panel display industry is a promising business model, to which management scholars have paid little attention. The adoption of interdependency view helps to examine how interfirm relationships affect a technological laggard's technology deployment decision. On one hand, interfirm relationships generally facilitate the flow of knowledge and increase a laggard's innovation output. On the

[46] Technology=invention + commercialization

other hand, a laggard may refrain from moving ahead of its partner to avoid competitive responses. The tension within the literature in this regard has not been inadequately addressed.

Finally, it would also be useful to explore different strategies that a technological laggard can or shall use besides moving towards or to the technology frontier (Christensen & Rosenbloom, 1995). For instance, when the technological leader's technology is too cutting-edge, a technological laggard may opt to shadow the technological leader rather than move to the technology frontier. The current model of organizational capabilities and economic incentive may be useful to study how a technological leader can become a laggard, and vice versa.

**7.3 Contributions**

Most technology studies consider innovation and competition (Adner & Zemsky, 2005; Aghion *et al*., 2005; Gilbert, 2006; Horner, 2003; Tang, 2006; Vaaler & McNamara, 2010), or considers innovation and organizational capabilities (Berry, 2006; Blundell *et al*., 1999; de Figueiredo & Teece, 1996; Penner-Hahn & Shaver, 2005). This dissertation contributes to the literature by simultaneously considering firm capabilities, competition, and innovation, which is a rather unique approach that only a few studies have adopted before (Leiblein & Madsen, 2009).

Support for the theoretical model in the current study contributes to the extant literature in several ways. Following Lerner (1997) that uses technological capabilities to explain the relationship between firms and the technology frontier, this dissertation helps to explain and predict how a technological laggard's organizational capabilities affects its position relative to technology frontier. The empirical findings underscore the role of the focal firm's organizational capabilities in the competitive dynamics research (Lamberg *et al*., 2009; Sirmon *et al*., 2007). The move of technological laggard depends not only on the strength of its capabilities but also on the types of capabilities that it has.

This dissertation contributes to the competitive dynamics literature by highlighting special circumstances where market competition effectively encourages a technological laggard to innovate. Highlighting these special circumstances helps to resolve the conflicting predictions on whether the competition leads to more innovation (Aghion *et al*., 2001; Tang, 2006). Furthermore, this dissertation also contributes to studies on organization decision making. Empirical results in this dissertation suggest that a technological laggard is indeed able to behave rationally in deciding which technology to deploy so that it can achieve the anticipated economic payoff. An economic rationale introduced in this dissertation also resolves the debate on whether a large market share leads to inertia or innovation momentum.

Lastly, this dissertation provides useful managerial implications for managers at the technological lagging firms. Laggard firms are often the majority in an industry. The implications from this dissertation directly address the issues managers in these laggard firms may face. The broader implication of this study for technology strategy is that technological laggards are a distinct, yet heterogeneous group, where the anticipated economic payoff largely determines whether to attempt to move to the technology frontier. Beyond that, this study also highlights the capability heterogeneity among technological laggards. Addressing the issue of heterogeneity helps to explain and predict a laggard's firm behavior with respect to technology deployment. Future research on technological laggards will need to branch out from firm capabilities and competitive dynamics researches to further develop the laggard strategy.

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