Technology Advancement and Firm Performance: A Study of Sales Growth in the Flat Panel Display Industry

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Abstract

Firms pursue newer generations of technology in the hope of increasing sales, but the effect of this technology advancement strategy on sales growth is undetermined, because the resulting technological change often creates disruptions to the firm and its competition environment. We posit that understanding the effectiveness of a firm’s technology advancement strategy requires that we examine the contextual factors particularly associated with this type of technological change. Using data from the global flat panel display industry, we find that longer tenure in the industry, a lower level of technological innovativeness, or greater product overlap with competitors helps a firm benefit from its technology advancement. We contribute to the innovation literature by highlighting the interdependence between a firm’s innovation strategy and contingencies favoring performance improvement.
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Keywords: Generational technological change; technology advancement; sales growth; technological innovativeness; product overlap
INTRODUCTION

Generational technological change represents “a significant advance in technical performance within a technology regime” (Lawless and Anderson, 1996: 1187). Technology advancement in the form of generational technology innovation is an important yet understudied element of innovation strategy (Lawless and Anderson, 1996; Turner, Mitchell, and Bettis, 2010). Even less scholarly attention has been paid to the performance implications of this type of technology innovation. Firms pursue technology advancement by deploying a technology generation more advanced than its current technology in the hope of increasing sales, but the impact of this strategy on sales growth is undetermined. On the one hand, because a newer technology generation does not completely destroy the innovation value of older ones (Lawless and Anderson, 1996), technology advancement creates opportunities for a firm to not only enter new market segments and attract new customers, but also better serve its current customers (Banbury and Mitchell, 1995). On the other hand, because a newer generation of technology still requires R&D investment more substantial than intra-generation technological innovations, deploying a new technology generation may pose organizational challenges and cause disruptions to the firm (Swift, 2015). Worse yet, technology advancement may even change the status quo with regard to competitors and disrupt a firm’s competition environment (Barnett and Sorenson, 2002), encouraging competitors to engage in a technology race in which they also advance their technologies. The tradeoff inherent in the technology advancement strategy raises the following question: How can firms strategize to gain sales growth through technology advancement?

Although scholars have paid much attention to the broad relationship between innovation and firm growth (e.g., Aghion and Howitt, 1992; Coad and Rao, 2008; Del Monte and Papagni, 2003; García-Manjóna and Romero-Merino, 2012; Geroski, 2005; Talay and Townsend, 2015),
empirical evidence regarding the effect of innovation on firm growth is still mixed (Corsino and Gabriele, 2011). We posit that the effect of innovation on firm growth depends upon the internal and external environment of the firm (Talay and Townsend, 2015), so does the effect of technology advancement, which is a particular form of firm innovation that pertains to generational technological change. To better understand the relationship between technology advancement and firm growth, we need to identify relevant contextual factors and examine how they affect the effectiveness of a firm’s technology advancement strategy.

Firm growth is influenced by aspects of its internal environment, such as tenure in the industry (Chen, Williams, and Agarwal, 2012), as well as factors associated with a firm’s external environment, such as the status of its technological innovativeness relative to its rivals (Stuart, 2000), and the intensity of market competition (Gimeno and Woo, 1996). We posit that these contextual factors – firm tenure in the industry, status of a firm’s technological innovativeness, and the extent of market competition – are particularly relevant in the context of generational technological change. We posit that these factors will not only affect firm growth themselves, but also impact the effectiveness of a firm’s technology advancement strategy by negating disruptions the strategy may cause to the firm and its competition environment.

We situate our empirical testing in the global flat panel display industry, which is ideal for our focus on generational technological change (Lee, Kim, and Lim, 2011; Wang, Yang, and Miller, 2015). This industry has exhibited continuous technological progression since its inception. For example, Liquid-Crystal Display (LCD) technology moved from the 1st technology generation in 1990 to the 10th technology generation in 2010. The technology progression from the 1st to the 10th generation moves along one trajectory, with technical knowledge from prior generations often serving as the technical basis for deploying future generations. Moreover, flat panels have a wide
variety of product applications, making it possible for at least some aspects of older generations to coexist with newer generations. Our results show that a firm that has accumulated more time in the industry, occupies a lagging technology position, or encounters competitors in multiple product markets is likely to suffer in sales growth. However, we also find that firms may achieve higher sales growth via technology advancement when they have longer tenure in the industry, occupy a lagging technology position, or encounter competitors in multiple product markets.

Our research findings contribute to the innovation and technology management literature. First, they extend the existing research on the relationship between innovation and firm growth, pointing out that while trying to determine the effect of innovation on firm growth, researchers should take into account those contextual factors associated with the technology regimes in which a firm’s innovation strategy is embedded. Our finding that the effectiveness of technology advancement is context specific highlights the interdependence between a firm’s innovation strategy and its internal and external environment. Furthermore, it advances our understanding of generational technology considered by Lawless and Anderson (1996) as well as Turner et al. (2010) by examining not only the performance implications of technology advancement but also, more importantly, those contextual factors that enable a firm to benefit from technology advancement.

In what follows, we first discuss the conceptual background and develop our hypotheses. We then describe our methodology and report empirical results. We conclude with a discussion of our contributions and suggestions for future research.

**THEORY AND HYPOTHESES DEVELOPMENT**

**Conceptual background: generational technological change**

Ever since Tushman and Anderson’s (1986) seminal work on technological discontinuities, great scholarly attention has been paid to the difference between radical and incremental technological
Incremental technological change has appeared to be immune from the risks inherent in radical technological change, and disproportionately less scholarly attention has been devoted to examining the impact of incremental technological change on firm performance (McKendrick and Wade, 2010). We submit that incremental innovation varies greatly in terms of the extent of technological change and the associated organizational change; although some innovations are truly incremental, requiring no substantial change, technologically or organizationally, others may call for substantial technological reconfiguration or organizational restructuring. Different types of incremental technological changes, therefore, can affect firm performance differently.

Here we will study a particular form of incremental innovation: generational technological change. Lawless and Anderson (1996) consider generational technological change as an evolutionary force behind the punctuated equilibrium phenomenon, “a significant advance in technical performance within a technology regime” (p. 1187). Generational technological change differs from radical technological change, in that the former does not cause paradigmatic technical change and does not completely destroy the innovation value of older generations. Generational technological change differs from typical incremental change in that it requires substantial R&D investment and leads to substantial improvement in technical performance. Generational technological change can occur in the form of product innovation, as was pointed out in Lawless and Anderson’s (1996) study of different generations of microprocessors in the U.S. microcomputer market and Tuner et al.’s (2010) focus on business productivity software products. Generational technological change may also occur in the form of production technology innovation, such as Lee et al. (2011) examined in the different generations of production technologies in the flat panel display industry, and Banker et al. (2013) studied in research on
technology progression from 2G to 3G in the telecommunication industry. Whether different generations of products or different generations of production technologies, generational technological change exhibits *technological continuity* across technology generations, in that older may coexist with newer generations (Nair and Ahlstrom, 2003; Lawless and Anderson, 1996).

**Technology advancement: its undetermined effect on firm sales growth**

Existing studies have found a positive effect (e.g., R&D intensity in García-Manjóna and Romero-Merino 2012) or no effect (e.g., product/process innovation in Geroski and Machin, 1993, and product innovation in Bottazzi et al., 2001) of innovation on firm sales growth; thus in the context of generational technological change, the effects of technology advancement on sales growth are undetermined. On the one hand, because such technological change is non-radical, it is possible for firms to both attract new demand and retain old customers after advancing to newer generations, therefore firms can leverage technological knowledge from the newer generation to improve performance of older generations, which help to increase their overall production efficiency and product performance. On the other hand, however, technology advancement is not a simple incremental innovation, as the former still requires substantial investment in R&D, organizational learning, and structural changes, all of which may lead to adjustment costs for the firm and possibly drain managerial resources. For example, McKendrick and Wade (2010) found that small firms are more likely than large firms to suffer from organizational disruptions caused by frequent incremental changes, suggesting that non-radical innovation can also create disruptions to some firms. In addition to organizational disruptions, technology advancement of a focal firm may also disrupt the status quo of its competition environment, to the extent that competitors become aware and motivated to counteract with competitive moves (Chen and Li-Hua, 2011).
To be able to better predict the effect of technology advancement on sales growth, it is therefore useful to identify factors that can strengthen the positive influence or negate the negative influence of technology advancement on sales growth. Consistent with prior literature, we identify the following three factors that are particularly relevant to a technology regime characterized by generational technological change: firm tenure in the industry (Chen et al., 2012), extent of a firm’s technological innovativeness relative to its rivals’ (Appleyard, Hatch, and Mowery, 2000), and a firm’s product overlap with competitors (Gimeno and Woo, 1996). First, because of the technological continuity across technology generations, a firm’s accumulated experience through operating older generations can be redeployed if the firm decides to deploy a newer technology generation (Helfat and Eisenhardt, 2004). Second, the presence of multiple technological generations forms a technology ladder within the industry, placing firms deploying different generations on different rungs of the ladder. Using the distance among rungs, a firm can gauge not only its own strategic position in relation to competitors, but also any competitor’s. Such explicit knowledge of each other’s competitive position makes it easy for one firm to discern another firm’s strategic move, and vice versa. Third, the co-existence of different generations of technologies lead to the co-existence of different products based upon different technology generations (Lawless and Anderson, 1996). Thus firms encounter each other not only across different technology generations, but also across different product markets.

Below we will develop a framework to understand how these contextual factors affect the effectiveness of a firm’s technology advancement strategy in its pursuit of sales growth. Before we develop these hypotheses on moderating effect, we will lay out the baseline hypotheses to directly predict the three contextual factors' effect on sales growth.
**Firm tenure in the industry**

Firm growth exhibits a lifecycle effect, where firm growth decreases with firm age (Evans, 1987). In general, when a firm ages, its business practices are imprinted in the organization and become more difficult to alter. This is because older firms tend to prefer exploiting existing routines instead of exploring new ones (Nelson and Winter, 1982). Thus organizational routines initially adopted to help develop firm capabilities may lead to organizational rigidities (Leonard-Barton, 1992). For example, routinized internal operation processes constrain a firm’s ability to implement strategic change, such as launching a new product, while routinized decision-making processes may give rise to internal politics that hinder efficient resource allocation (de Figueiredo, Rawley, and Rider, 2015). This lifecycle effect of firm growth is even more salient when we relate it to the “focal industry environmental conditions and the accumulation of routines and commitments within the industry” (Chen et al., 2012: 257). Having operated in an industry for an extended period of time, a firm is likely to have established relationships with its customers, suppliers and complementors, which could create a semi-closed network within a segment of a particular industry (Appleyard, 2003). Such networks may prevent the firm from scanning or seeing new market opportunities (Christensen, 1997). Even if the firm sees growth opportunities in a new market, its obligations to existing stakeholders make it difficult to seize new opportunities. Younger firms, on the contrary, are less embedded in the industry-specific environment and, hence, have a greater flexibility in strategic maneuvering, such as reallocating resources to new market applications (Chen et al., 2012). Thus, we predict that:

*H1a: Firm tenure in a focal industry is likely to decrease its sales growth.*

Being old will not always slow down sales growth if a firm can optimize strategic change by leveraging its experience. While organizational rigidities represent the downside of firm tenure, value can be derived from tenure to create a positive effect on sales growth, particularly in the
context of generational technological change. First, longer tenure in the focal industry provides greater inter-temporal economies of scope that firms can leverage over time through redeploying resources from old business to new business (Helfat and Eisenhardt, 2004). In the context of generational technological change, technology of newer generations is improved based on current technology and does not completely replace older generations. Firm resources and capabilities accumulated in operating with prior generation technology can still be redeployed to the newer generation. For example, while semiconductor manufacturers compete to meet Moore’s Law, the techniques required for operating photolithography equipment largely remain unchanged. In building a narrower line width, a firm may deploy a new set of equipment and new chemical compound, while still employing similar processes to produce photo resistor on the wafer. The knowledge of photolithography is what firms can carry from older to newer generations, including not only physical resources and assets but also operational capabilities and managerial capabilities. The longer a firm operates in an industry, the greater the amount of resource and capabilities that can be reallocated and repurposed from prior technologies. By combing the older with the newer resources and capabilities, the firm is able to achieve synergistic effect from the inter-temporal economies of scope. Younger firms, however, are less able to benefit from these inter-temporal economies of scope.

Second, the longer a firm exists in an industry, the more experience and knowledge it accumulates (Adner and Kapoor, 2010), enabling it to develop organizational capabilities to predict and manage competition (Smith, Ferrier, and Ndofor, 2001). This can be done through two mechanisms. One is to lower uncertainties through better prediction of industry demand. With more experience in the industry, a firm is likely to be more capable of predicting the business cycle within it. For example, Intel, under the guidance of Andy Groove, was able to time the demand
of the next generation for its product release (Burgelman, 2002). A firm can mitigate losses when its inexperienced competitors slash prices to unload inventory resulting from gluts. Similarly, an experienced firm is likely better at predicting the timing of a demand bounce following a downturn, resulting in knowledge of when to invest early to gain more in sales before its competitors. The second mechanism is through better competition management. A firm with longer tenure in the industry likely has competed with most firms and can develop knowledge specific to each competitor. This “competitor’s acumen” enables the firm to better predict and respond to competitors’ actions (Chen, Su, and Tsai, 2007). The firm will then know which firms are serious competitors and prepare for aggressive attacks from them. Experience helps a firm to avoid costly competitive battles while taking advantage of weaker competition. Overall, the ability to better predict demand and manage competition helps the firm to better time its technology advancement, and achieve higher sales growth through its technology advancement.

In all, we argue that a firm with long tenure in the industry is better able to manage disruptions to its organizational and its competition environment resulted from technology advancement than one with short tenure.

Hypothesis 1b: Firm tenure positively moderates the relationship between technology advancement and sales growth.

Status of technological innovativeness: technological rank

In an industry based on generational production technology, firms are, in effect, placed upon a ladder where each rung represents different levels of technological innovativeness, with the top of the ladder being the most advanced technology and the bottom representing the least advanced technology deployed in the industry. A firm’s technological position in this hierarchy can be derived by referencing its level of technical innovativeness as indicated by its distance to the industry frontier (Appleyard et al., 2008). Firms can be ranked based upon their existing
technology (Appleyard et al., 2000; de Figueiredo and Teece, 1996). Such an ordinal ranking of each firm’s technology captures the variation in the firms’ status of technology innovativeness.

The ranking of a firm’s technological innovativeness is associated with its sales growth, as technology determines the specification and unique features of the resultant product. Technology innovativeness is able to elevate the firm’s reputation in the eyes of existing and potential customers, suppliers and investors (Stuart, 2000). Because of the greater technical performance packed into the products, firms with greater technological innovativeness are able to charge higher prices. Put differently, firms running higher technology generations in their production facilities are more likely to enjoy higher sales revenue from the same sales volume. For example, Lawless and Anderson (1996) found that firms with greater technological innovativeness outperform their close competitors in market share. Further, firms running higher technology generations are likely to have higher status because a high rank may also create a halo for the firm. This halo effect is in addition to the direct benefit associated with higher quality or better features that are likely to attract more customers. Thus:

\[ H2a: \text{A high technological ranking is likely to increase a firm’s sales growth.} \]

Firms ranked lower on the generational technology ladder carry lower technological status in the industry, but they also have more room for strategic maneuvering with respect to technology advancement. In the context of generational technological change, a firm closer to the industry technology frontier has fewer possible rungs to climb and likely faces greater difficulty when moving up generations because its current technology is already fairly sophisticated. Therefore, the advancement from the current technology to the frontier may require sizable resource outlays to overcome technological challenges (Lee and Kim 2013). On
the contrary, a lower ranked firm has more room to improve its technology than its higher rank counterpart, often at less cost as well.

Generally, we posit that a lower ranked firm (i.e., technological laggard) will achieve greater sales growth from technology advancement than higher ranked firms. Technology advancement for a lower ranked firm typically means deploying a technology generation that is newer than its current generations, but has already been deployed by other firms before. This puts the firm as a late-mover. Being a later comer to a known technology, the lower ranked firm can take advantage of proceeding firms’ experience, not only in terms of the technological knowledge for manufacturing, but also in terms of the demand characteristics (Lieberman and Montgomery, 1988). For example, it is highly difficult for flat panel makers to predict which panel size will be more popular before commencing a new plant. Based on the interviews with industry participants, the first panel maker will have to predict, literally guess, which TV specification will be more popular, for example, 36” vs. 37”. An incorrect prediction will prove detrimental to projected sales. When a lower ranked firm advances its technology, the market has been tested and the most popular product configuration has been found. In essence, a low ranked firm can wait for more appropriate timing for technology advancement (Agarwal, Sarkar, and Echambadi, 2002). The same logic applies to a firm far behind the industry average, which can still make a small advancement from its current lagging position. When advancing its technology to a newer generation, a lower ranked firm is able to generate more sales by identifying more product applications with its new technology (Mathews, 2005) and implementing more fine-tuning to the technology to improve product performance. Technological performance from incremental improvements usually allows a firm to command a higher price point of the similar specification, leading to more sales.
Further, because of its lagging position in the technological ranking, strategic maneuvering by a lower ranked firm poses a less visible threat to competitors (MacMillan, McCaffery, and van Wijk, 1985) than a higher ranked firm would. In the absence of a competitive response, a lower ranked firm has a window of opportunity to gain more sales from technology advancement than a higher ranked firm. In all, we argue that a lower ranked firm is likely to suffer lower technological uncertainties, lower market uncertainties, and arouses less awareness or motivation for competitors to engage in a pernicious technology race. Thus:

*Hypothesis 2b: A low technological ranking positively moderates the relationship between technology advancement and sales growth.*

**Product overlap**

The existence of different generations of technologies leads to different product markets in an industry. A firm can simultaneously compete in multiple product markets, where the firm encounters competitors. The extent to which a focal firm competes in the same product market with other firms in the industry indicates the extent of product overlap (Gimeno, Chen, and Bae, 2006) and competitive rivalry (Anand, Mesquita, and Vassolo, 2009). The higher the product overlap, the greater the competitive rivalry, which is one of the most important industry factors that determine firm sales (Porter, 1980). The more intense the price competition a firm encounters, the less likely the firm will achieve higher sales growth within its product markets.

*Hypothesis 3a: The extent of product overlap with competitors is likely to weaken a firm’s sales growth.*

As Gimeno, Chen, and Bae (2006: 408) point out, “[h]ighly dependent firms may learn to live and let live by developing strategies to avoid direct conflict.” With a “sphere of influence” a firm may hold off action (Gimeno, 1999). Though a firm can pursue a truce with its competitors across product markets, a firm needs to address the competitive pressure to protect its market
position in the long term. Instead of initiating head-to-head competitive action within product markets, e.g., price cuts common in the airlines industry (Gimeno and Woo, 1996), a firm can choose alternative actions like technology advancement that is less of a direct competitive threat for its competitors in the existing product markets and is less likely to trigger competitive retaliation (Markman, Gianiodis, and Buchholtz, 2009). Further, technology advancement can increase product differentiation, which allows a firm to reduce the level of competitive interdependence with its closest competitors (Dobrev, Kim, and Hannan, 2003). Reduction in interdependence can then decrease the intensity of competition (McPherson and Rotolo, 1996), thereby lowering sales erosion. In other words, technology advancement allows a firm to reduce competitive pressure without directly irritating competitors who currently have high product overlap with the focal firm. In all, we have:

Hypothesis 3b: The extent of product overlap with competitors positively moderates the relationship between technology advancement and sales growth.

Figure 1 summarizes the hypotheses.

[Insert Figure 1 about here]

METHODS

Empirical context: the flat panel display industry

The flat panel display industry has seen continuous generational technological changes since commercial production of flat panel began in 1989 (Mathews, 2005). Below we discuss two important aspects of this industry relevant to our operationalization: technology progression and product application.

Indicator of technology progression: flat panel generation

Flat panel displays are manufactured on large sheets of glass substrates, which are subsequently divided into individual display panels. The more advanced the technology generation, the larger
the size of substrate and the more display panels it can yield, achieving greater economies of scale. Also, profit margins increase with the size of panel. For example, with the same technical specification, the price for a 52" panel is $2,345, $643 for a 32" piece, and $97 for a 26-28" piece (DisplaySearch, 2008). Figure 2 summarizes the generations of TFT-LCD (Thin-Film-Transistor Liquid-Crystal Display) technologies deployed by all firms. Even with newer generations emerging, older generations do not exit quickly, though new deployment of older generations does show a slowdown. For example, Generation 1 continued to be utilized in 2010, but new deployments of Generation 1 or 2 died down after the early 2000s. The industry as a whole has exhibited an increasingly divergent distribution of production technologies over time, with newer generation technologies being deployed while older generation technologies still persist.

[Insert Figure 2 about here]

Technology in market: product applications

After manufacturing is completed, the glass substrate is divided into display panels. The panel size largely determines the final product application (Hu, 2012). Our data cover 19 product applications – audio player, camcorder, camera, cell phone, DVD player, game console, in-vehicle, industrial monitor, notebook, personal computer, pachinko, pachislo, projector, public outdoor display, smart phone, rear projection TV, HDTV and TV (20- to 60-inch). Figure 3 illustrates key product applications by its graph array (pixel count) and display size (inch). Smaller displays tend to have more general applications. The size of the bubbles in Figure 3 represents the number of firms supplying a particular product, suggesting that some applications have more supplying firms, such as TV, HDTV, notebook and industrial monitors.

[Insert Figure 3 about here]

Data sources
We collected and compiled data primarily from the annual publication by Fuji Chimera (Japan), “Flat Panel Display Applications: Trend and Forecast,” which covers the years from 1990 to 2011. These annual reports provide production and market-related data for all firms in the flat panel display industry. The second data source is “Dynamics of Flat Panel Display Industry,” published annually by the Photonics Industry and Technology Development Association (Taiwan) from 1991 through 2010, with a primary focus on Taiwanese and Chinese firms. Supplemental data sources include the Nikkei Microdevices’ “Flat Panel Display Yearbook,” published in 1997 and 1998, which consists of data before 1998. The final dataset has 450 firm-year observations.

Variable definitions

Dependent variable

Sales growth measures the annual growth of sales at firm level. Here the sales number captures a firm’s total production values of flat panel displays. Because the size of growth could vary with firm size, we divide the growth, $Sales_{it+1} - Sales_{it}$, with the firm’s sales in year $t$. Formally the sales growth for firm $i$ in year $t$ is defined as:

$$Sales\ growth_{it} = \frac{Sales_{it+1} - Sales_{it}}{Sales_{it}}$$

Following prior studies drawing data from the flat panel display industry, we measure the sales growth by a one year gap (Lee and Kim, 2013), i.e., one year after the deployment of a newer technology generation, for two reasons. One, products using the newly deployed technology typically will be supplied to the market soon after the commencement of the deployment, and thus, the sales data in the following year can rightly reflect the impact of technology advancement. Two, the flat panel display industry can have very volatile demand (Lee et al., 2011; Lee and Kim, 2013), which creates noise if the gap is too wide.
Independent variables

*Technology advancement* is a binary variable, equal to 1 if a firm deploys a technology generation more advanced than the one it started the year with; 0 otherwise. We consider a firm to deploy a new technology if it commences production with that technology generation.

*Firm tenure* measures the number of years a firm has been operating since it opened its first plant in the flat panel display industry.

*Technological rank* measures a firm’s level of technological innovativeness in relation to its competitors’. We rank firms by their highest generation deployed in a given year. The higher the generation, the higher is a firm’s status of technological innovativeness and the smaller the rank number a firm receives. If firms deploy the same generation, they will have the same ranking. For instance, in 2008 Samsung and AUO both deployed the latest Generation 8.5. So Samsung and AUO both received #1 in ranking that year. Sharp deployed Generation 8 and so received #3 in ranking; CMO and LG deployed Generation 7.5, and both received #4 in ranking.

*Product overlap* measures the degree of multipoint contact between a focal firm and all other competitors in the industry in a given year. We calculate the number of firms sharing the same product with the focal firm, divided by the number of products the focal firm produces. Following Baum and Korn (1996), we operationalize product overlap as following:

\[
\text{Product overlap}_{it} = \sum_{i \neq j} \frac{\sum_{p} (D_{ipt} \times D_{jpt})}{\sum_{p} D_{ipt}}
\]

where \( p \) denotes a given product in a set of potential products \( P \), \( D_{ipt} \) is an indicator variable equal to 1 if firm \( i \) gains sales from product \( p \) in year \( t \) and 0 otherwise. \( D_{jpt} \) is an indicator variable equal to 1 if firm \( j \) gains sales from selling product \( p \) in year \( t \) and 0 otherwise.

Control variables
We control for firm characteristics and other environmental factors that can potentially influence technology advancement decisions of a focal firm. In terms of firm characteristics: 1) This industry has three clearly defined market segments: “large” for TV and outdoor displays, “medium” for computer monitors and laptops, “small” for mobile devices and instrument panels. We control for the effect of economies of scope by including a firm’s total number of active market segments. 2) Firm financial performance is likely to affect a firm’s risk-taking attitude. We control this by including a firm’s return on assets (ROA) in the current year. 3) Economies of scale typically encourage a firm to innovate due to better expected return on innovation (Mas-Ruiz and Ruiz-Moreno, 2011). We control for this by including market share, the ratio of a firm’s production value to the industry’s total production value in a given year. 4) We include firm size to control for the amount of overall organizational resources available to the focal firm, using annual assets (log) in a given year. 5) We also include a firm’s patent stock, the logged total number of patents the firm has received in International Patent Classification sections F21V, G02F, G09G, G09F, H01J, H01L, H04N, H05B, H05H in each year (Spencer, 2003). 6) We have a diversification measure to capture the difference between firms dedicated to flat panels and business units in larger conglomerates: 1 indicates the manufacturer is a unit in a conglomerate and 0 otherwise. 7) Our sample includes 4 firms operating both liquid crystal display (LCD) and organic light-emitting diode (OLED). To control for the dual trajectory effect, we include a dummy, coded 1 if the focal firm earns sales from OLCD and OLED and 0 otherwise. 8) Whether a firm advances technology in the past year can affect its decision to advance in the current year. We control for past movement, with a dummy variable equal to 1 if a firm has deployed a higher generation in year $t-1$, otherwise it is 0. 9) We added nationality
dummies to control for the effect of government policies on capital markets and research consortia, with the coding based on the location of a firm’s headquarters.

Model

Because test statistics raised concerns about autocorrelation and heteroskedasticity, we fitted panel-data linear models using feasible generalized least squares (FGLS), which allows for estimation in the presence of AR(1) autocorrelation within panels and cross-sectional correlation and heteroskedasticity across panels (Afuah, 2001). FGLS is generalized least square for panel data, assuming some structure for the distribution of $e(i, t)$ without user directly specifying fixed or random effects. Compared with other linear regression models, FGLS estimates are more efficient and hence preferred (Wiggins, 1999).

Results

Table 1 reports summary statistics and correlations. The model’s mean variance inflation factor (VIF) is 1.63, and the max VIF for product overlap is 2.34, both below 10, the commonly accepted value (Chatterjee and Hadi, 2006). Table 2 has the FGLS model for hypothesis testing.

| Insert Table 1 and 2 here |

We first examine the results of the hypothesized direct effects (H1a, H2a, and H3a), using Model 1. Hypothesis 1a fails to receive statistical support. The coefficient of firm tenure is positive and significant ($\beta=0.027$, p-value<0.1, Model 1), suggesting that older firms report higher sales growth than younger firms. Although firm tenure in our sample ranges from 1 to 19, 50% of the observations are below 7 and only 10% of observations are greater than 14. With majority of observations being younger than average, our sample might lack the variance needed to test the effect of organizational inertia as we hypothesized. It is possible that older firms likely

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1 The result of a Breusch-Pagan/Cook-Weisberg test for heteroskedasticity is $\beta=887.22$ (p-value=0.000), rejecting the null hypothesis that variance is constant. The result of a Wooldridge test for autocorrelation in panel data is $F(1, 52)=7.235$ (p-value=0.0096), rejecting the null hypothesis of no first-order autocorrelation.
to have established relationships with more customers and suppliers that give them an edge to garner more sales in a short period of time than younger firms.

Hypothesis 2a receives statistical support, with the coefficient of technological rank being negative and significant in Model 1 ($\beta=-0.022$, p-value<0.001). A firm that is high in technological innovativeness receives a higher ranking, suggesting that products produced by a high ranked firm will attract more demand, leading to a higher sales growth.

As predicted, Hypothesis 3a receives statistical support. The coefficient of product overlap is negative and significant ($\beta=-0.018$, p-value<0.001, Model 1), corroborating that market overlaps between the focal firm and its competitors intensifies competition, which reduces the extent of sales growth. Alternatively, a firm is less likely to gain more sales when its product offerings are largely similar to those of competitors.

Models 2-4 test and find support for the hypothesized moderating effects (H1b, H2b, and H3b). Figures 4(a)-(c) report the post-estimation by Models 2-4, respectively.

Hypothesis 1b receives statistical support. The coefficient of the interaction term technology advancement x firm tenure is positive and significant ($\beta=0.051$, p-value<0.05, Model 2), corroborating the prediction that firm tenure strengthens the effect of technology advancement on sales growth. This finding suggests that older firms are more knowledgeable about the market and competition, and are savvier with the timing of technology advancement than younger firms. For instance, after experiencing bouts of booms and busts, experienced panel makers will know not to rush into investing in expansion when demand is strong to avoid a supply glut. Post estimation reports that of the firms advancing their technology, ones who are older than the industry mean report 0.2 greater sales growth than ones whose age are below the
mean. Figure 4(a) also demonstrates that sales growth for older firms top that of younger firms for age differentials of at least 15 years.

Hypothesis 2b also receives statistical support. The coefficient of the interaction term technology advancement x technological rank is positive and significant ($\beta=0.021$, p-value<0.05, Model 3), indicating that technological rank strengthens the effect of technology advancement on the sales growth. In Figure 4(b), the gain in sales growth increases with a higher value of the technological rank variable, i.e., technological lagging. For firms whose technological rank is behind the industry mean, their advancement will, on average, achieve 0.19 more growth rate in sales than firms with the same rank that chose not to advance the technology.

As predicted, Hypothesis 3b receives statistical support. The coefficient of the interaction term technology advancement x product overlap is positive and significant ($\beta=0.012$, p-value<0.05, Model 4), suggesting technology advancement can be a means for firms to seek differentiation. Differentiated product offerings will gain more sales because products can satisfy previously unmet demands. Figure 4(c) shows that technology-advancing firms that have high product overlap with competitors will exhibit more sales growth than firms with low overlap. The gains in sales are more substantial for firms with product overlap higher than the industry average. This finding corroborates our prediction regarding a firm using a less direct response to competition in the product market.

Regarding control variables that received statistical significance, the coefficient of technology advancement is negative and significant, suggesting that technology advancement reduces a firm’s sales growth. Industry-specific attributes of the flat panel industry may help to explain this. Indeed, different panel makers tend to advance their technologies within the same time period. Such a pattern narrows the opportunity of achieving higher sales growth for any
specific firm, because the industry output often sharply rises after a number of firms commence operation around the same time. The increase in supply only aggregates the glut, especially when demand fluctuation is the norm in this industry. Hence, it is possible that we could observe slowing of a firm’s sales growth after its technology advancement. Though this finding is not incompatible with prior studies on the mixed effect of innovation on sales growth, it begs the question, “How could firms deploy more advanced technologies in an effective way?” Our findings on the important moderating effect of a firm’s internal as well as external environmental factors provide partial answers to this question. The number of segments has a negative effect on sales growth, suggesting that perhaps in this technology context the cost of managing multiple market segments offsets the cost savings from economies of scope. Market share is negative, indicating firms with larger market share gain less in sales growth than those with a lower market share. Indeed, if a firm has already acquired a significant proportion of the market, additional customer acquisition will likely be more difficult. Lastly, past movement is negative, suggesting that if a firm has two technology advancements in a row, its efficiency in improving sales may be constrained by availability of managerial resources (Penrose, 1995).

**IMPLICATIONS AND CONCLUSIONS**

Intrigued by the mixed evidence about the effect of innovation on firm growth from the vast innovation literature, we studied three contingent factors that may affect the effectiveness of a particular form of innovation, technology advancement, in the context of generational technological change. Our findings show that although a firm’s technology advancement in itself may weaken the firm’s sales growth, several contingent factors – firm tenure in the industry, technological rank, and product overlap – weaken the negative effects of technology advancement on sales growth. Because of the continuity of technological change in generational
technological change, a firm’s industrial experience becomes valuable in managing technology advancement, the technology trajectory in the industry clearly defines a firm’s technology position, and the backward compatibility of newer technology generations with older generations intensifies competition across different product markets. These factors, over time, contribute to firm heterogeneity, which has a substantial impact on the effectiveness of a firm’s technology advancement strategy. For example, the experience and reputation of a firm among stakeholders may enable it to incur lower adjustment costs and less managerial resource drainage associated with generational technological change. This resonates with McKendrick and Wade’s (2010) argument that frequent incremental change creates organizational disruption but large firms are more able to benefit from incremental innovation than firms. Overall, our findings help to provide a more holistic view of the role that technological innovation plays in driving sales growth in the context of generational technological change (Lawless and Anderson, 1996).

This paper makes three contributions to the literature on innovation and firm performance. First, our findings show that the effectiveness of a firm’s innovation strategy may well depend upon the firm environment (internal and external) where the innovation takes place. Although prior research has attempted to capture the variation in firm environment (e.g., high-technology sectors vs. non-high-technology sectors in García-Manjóna and Romero-Merino, 2012; corporate vs business unit operation in Corsino and Gabriele, 2010; and large firms vs. small firms in McKendrick and Wade, 2010), our findings on the contingent role of firm tenure, technological ranking, and product overlap shows that a finer-grained approach is necessary for better understanding the environmental effect. Our study exemplifies such an approach, by examining three contextual factors particularly relevant to the technology advancement strategy in the context of generational technological change. Without considering these contextual factors, one
may erroneously conclude that technology advancement may hinder sales growth, and resort to industry specific attributes to support this conclusion.

The second contribution to the innovation literature relates to the type of innovation. Although various indicators of innovation have been used in prior literature, such as R&D intensity (García-Manjóna and Romero-Merino, 2012), product/process innovation (Geroski and Mazzucato, 2002), and product innovation (Bottazzi et al., 2001), the context-specific attributes of an innovation indicator have often been neglected. Our paper submits that in order to understand the effectiveness of innovation on firm sales growth, it is imperative to articulate the attributes of the innovation under study. Indeed, because of its focus on generational technological change, our study is able to spell out several features of this type of innovation (e.g., co-existence of old and new technology generations, inter-temporal economies, backward compatibility of technologies, and multiple product applications using different generations of technology) that make the three contingent factors relevant.

In this regard, our study advances the understanding of generational technology considered by Lawless and Anderson (1996) as well as Turner et al. (2010). Although generational technological changes occur in numerous industries, the extant literature does not offer an understanding of generational technology equivalent to our knowledge about radical innovation. The innovation literature has commonly categorized technology as either radical or incremental, and tends to dismiss the variations within incremental innovations. This study delves into a particular form of incremental innovation, i.e., generational technology, to highlight several of its context-specific attributes. Although technology of a newer generation is not radical because the technology is not entirely new, neither is it a simple incremental change, because each new generation invokes a new round of investments in research and equipment, as evidenced in the
Our third contribution to the innovation literature relates to the importance of a firm’s capability in innovation management. We show that a firm’s capability to create and capture value from technology advancement can be accumulated through longer tenure and greater exposure to competitors in product markets. Even if a young firm can play catchup to accelerate the building of its technological innovativeness, it lacks what incumbents derive from their tenure: better knowledge of the customer, demand, and competitors. These firm-level attributes are complementary to value creation/capturing through technology innovation (Teece, 1986), contributing to sales growth. For old firms, even though they may suffer inertia and inflexibility caused by aging, it is still advantageous for them to leverage their organizational attributes accumulated over time toward building their competitive edge. Moreover, our finding of a low-ranked firm scoring more sales from technology advancement suggests a different stream of thinking in innovation management. If we ask who should innovate the most aggressively and first, the common answer will be the technological leader (Aghion et al., 2005), who is inclined to deploy the latest technology to maintain its technological dominance. Nevertheless, firms with leading technological position in the flat panel display industry often experience poor financial performance. For example, Sharp, Samsung and AU Optronics are all technological leaders that invest heavily in R&D and facilities. In 2012, Sharp reported the largest loss ($4.67 billion) in its history. Samsung spun off its LCD division after losses of $9.67 billion in the single year of 2011. AU Optronics posted losses four years in a row even as it recorded its largest-ever sales during the same period. Our study suggests that those firms in backward technological positions, the very group of firms considered having lost the technology race (Barnett and McKendrick, 2004), can actually gain from innovating, at least in sales growth. This finding returns the focus
to who should really innovate, and illuminates the motivations for innovating.

Several limitations in this study provide research opportunity. First, our findings are derived from a single industry; thus generalizing our results and interpretations must be done with caution. Future studies can examine the same research questions in similar industry contexts with generational technological change, such as the semiconductor industry and the disk drive industry, to evaluate the generalization potential of our findings. Second, in this paper technology advancement is treated as a dummy variable, which may omit some rich strategic implications of a firm’s technology advancement strategy. More insights will be revealed if future studies adopt a continuous measure, such as the timing of technology advancement and the duration of implementing technology advancement. Third, due to data limitations, we measure a firm’s sales growth using its total production value, rather than sales a firm generates from each technology generation, or from each product application. Our approach is able to capture the overall effect of technology advancement on sales growth, but it would be interesting to examine how deployment of a newer technology generation affects a firm’s sales from each of its deployed technology generations in each product market, if data are available.

Whether innovation increases a firm’s sales growth has been an enduring scholarly inquiry, yet no conclusive evidence has been achieved. This paper suggests that instead of asking whether innovation increases firm sales growth, a more meaningful question is: for a specific type of innovation, what contingent factors can help a firm to gain from this innovation. In this study we explain and predict internal and external factors that are conducive to sales growth when firms advance to a more advanced technology in the context of generational technological change. With this newly gained insight, future work could further articulate the complicated relationship amongst generational technology, innovation and, eventually, firm performance.
REFERENCES


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### Table 2 Feasible generalized least squares linear model; dependent variable is sales growth

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<td>Advancement x technological rank</td>
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Z statistics in parentheses
+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001
Figure 1: Hypotheses overview

Figure 2: Generation distribution (1994 – 2010)
Figure 3: Display product and its specifications during observation years

Figure 4: Predicted moderating effects