# Product Innovation and Survival in a High-Tech Industry

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**Abstract** We investigate the relationship between product innovation and firm survival for a sample of 121 firms in a high-tech industry. We find that location near the technological frontier is an important determinant of firm survival. Firms that are located near the frontier are also more likely to be acquired than to exit by liquidation if they cannot survive as free-standing enterprises. This suggests that product location in the technology space acts as a signal of firm quality. Greater R&D efforts increase the probability of surviving; in the event that the firm does exit, however, its R&D efforts do not significantly influence whether it exits via acquisition or exits via liquidation.

**Keywords** Market positioning, Quality frontier, Firm survival, Competing risk model, High-technology industries

**JEL Classification** L10 – O33 – D49

## 1 Introduction

Why do innovators exit the market? And how do they exit, by liquidation or by being acquired? Our answer is based on the dual role of product innovation in shaping the survival rate of firms. On the one hand, the dominant effect of successful product innovation should be to increase a firm's survival rate. On the other hand, successful product innovation may provide an incentive for competitors to acquire the innovator, either because the latter is a threat to the incumbents, or because it represents an opportunity to assimilate rapidly a bundle of technical competencies that otherwise would be time consuming to develop in-house. Therefore, the second order effect of successful product innovation should be ultimately to shorten a firm's life duration.

We focus on 121 firms that form the core of the worldwide local area networking (LAN) switch equipment industry. We define successful product innovation as improvement that is located at or near the technological frontier of the market. Having information on the firms' mode of exit, by liquidation or by acquisition, we run a competing risk model to investigate the relationship between distance to the technological frontier and exit by liquidation or by acquisition. We find that successful innovation has a positive impact on the firm's life expectancy. However if a successful innovator exits the market, it does so (as would be expected) by being acquired rather than by liquidation. This result suggests that mergers and acquisitions are key to molding the boundaries of firms, determining market competition, and ultimately shaping the dynamics of industries.

The paper is organized as follows: Section 2 provides a review of the literature. In Section 3 we provide some background information on the LAN switch industry, describe the data sources and the variables that will be used in the empirical analysis, and develop the econometric model. Importantly, Subsection 3.2 presents the method of hedonic prices that are used to measure the distance to the technological frontier as a proxy for successful innovations and firm quality. Section 4 discusses the results. Section 5 concludes.

## 2 Literature Review

Schumpeterian competition as a process of innovation and selection is increasingly viewed as the key to achieve sustained aggregate economic growth, by screening out the least innovative firms and promoting the most agile ones (Caves, 1998). When innovation is understood in terms of productivity growth, it has been shown that exiting firms are mostly concentrated in the lowest part of the productivity distribution, suggesting that markets contribute to aggregate productivity growth by rightly selecting against inefficient firms (Baily, Hulten, and Campbell, 1992).[1]

When innovation is understood more directly, for example, in terms of R&D investments or new product innovation, a more complex pattern emerges. In fast changing industries, soon after entry firms have a lower probability of survival, but once the initial period has been passed, their life expectancy increases significantly (Audretsch, 1995; Audretsch and Mahmood, 1999). Cefis and Marsili (2006) find that innovative firms are more likely to survive than are non-innovative firms. Finally, the timing of innovation (Christensen, Suarez, and Utterback, 1998), commercial strategy and relatedness among business lines (Mitchell, 1991; Willard and Cooper, 1985), and

[1] A non-exhaustive list of contributions includes, among others, Haltiwanger (1997), Foster, Haltiwanger, Krizan, Hulten, Dean, and Harper (2001) for the United States, Griliches and Regev (1995) for Israel, and Aw, Chen, and Roberts (2001) for South Korea and Taiwan.

the nature of the technological regime (Audretsch, 1991) have a strong influence on the life duration of new firms. On the whole, the idea common to all of these contributions is that innovative firms should grow faster, be more profitable, and ultimately survive for longer (Geroski, 1995).

Alongside this neat stylized fact, however, there are many examples of innovative firms that fail to survive. Exit is far from being a homogeneous event. Although most firms exit by liquidation, some exit as a result of acquisitions. Exit by acquisition may be the result of innovators' being "too successful", at least from a technological viewpoint. For competitors, they represent a threat and also an opportunity to acquire valuable intangible capital and distinctive skills.

But as of today, few analyses have investigated the case of firms that are innovative but fail (Schary, 1991), and even fewer have examined the links between innovation and mode of exit (Siegfried and Evans, 1994; Perez, Llopis, and Llopis, 2005). To our knowledge, the contribution by Cockburn and Wagner (2007) is the only one to address this issue explicitly. It looks at the survival of a sample of 356 Internet-related firms in the aftermath of the dot-com bubble. Employing patent applications as an indicator of innovativeness, they find that possessing a large patent portfolio both increases the probability of survival and decreases the probability of exiting via merger or acquisition. Only those firms with a large share of highly cited patents are more likely to exit by acquisition. Given that citations are a good indication of patent quality (Hall, Jaffe, and

Trajtenberg, 2005), this switch in the sign reveals that acquired companies provide intangible capital of economic value.[2]

In this paper, we focus on product innovation. Product innovation is interesting for several reasons. On the one hand, product innovation may confer to firms a competitive advantage, which boosts the life duration of successful innovators. A substantial theoretical literature (Bonanno, 1987; Brander and Eaton, 1984; Schmalensee, 1978) explains how firms strategically locate their products with respect to competitors. Less evidence has been provided on the relationship between such strategies and firm survival.

Stavins (1995), for instance, analyzed the determinants of entry and exit in a sample of personal computer (PC) models and firms between 1976 and 1988. She found that models that are produced by old firms are more likely to survive and that more innovative firms experience higher survival rates. Greenstein and Wade (1998) carried out a similar study on a sample of computer mainframes between 1968 and 1982. Employing duration analysis, they found that older models had a lower chance of surviving in the market. Interestingly they also found that the hazard rate of the single model increases in the number of models in the adjacent market segment, which suggests, therefore, that location in crowded markets negatively affects the likelihood of product survival.

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[2] Yet this important result is only weakly significant from a statistical viewpoint, and hard to interpret from an economic one. As the authors acknowledge, the correlation between patenting and firm duration may reflect unobserved firm characteristics such as the quality of the firm's products and intangible assets other than the technology itself.

On the other hand, product innovation is also a signal of firm quality (Bontems and Meunier, 2006). Think, for example, of a market in which products are distinguished on the basis of their quality. High quality products are those located near the technological frontier; thus, their market positioning reveals the quality of firms. In this context, high quality firms are very likely to become acquisition targets for at least two reasons. First, acquiring high quality firms represents an opportunity for competitors to improve and expand their own productive resources quickly (Karim and Mitchell, 2000). Second, acquisition may be used to exclude potential rivals from preferential positions in the market. In this case, the goal of the merger is not to increase productivity or research efficiency, but to increase market power (Salant, Switzer, and Reynolds, 1983), or even to preempt mergers by rival companies (Brito, 2003).

The above remarks become even more relevant for highly dynamic sectors. In such sectors, young firms are more likely to be acquired by incumbents because of the threat they pose to them (Grandstrand and Sjolander, 1990). Filson and Gretz (2004) looked at product innovation in the case of the hard disk drive industry. They found that product generation and the maturity of the firm are important determinants of firm success. Moreover, they found that the type of outcome (i.e., firm growth versus acquisition) also depends on the type of product innovation done by the firm. This paper provides an empirical investigation of the firm-level attributes that determine a firm's exit from the market. By measuring product innovation on a vertical scale, we characterize each firm by its distance to the technological frontier in a rapidly changing industry: the LAN switch industry.

## 3 Survival and Innovation in the LAN Switch Industry

### 3.1 Schumpeterian Competition in the LAN Switch Industry

The Local Area Networking (LAN) switch equipment industry began in 1990 with the invention of the first switch for data communication. The LAN switch industry is interesting because its evolution provides the typical characteristics of Schumpeterian competition.

First, entry in the industry was initially slow, but it dramatically increased after 1993. The swarm of entrants consisted of three different types of firms: Incumbents from LAN-based markets (i.e., routers and hubs) entered the switch industry. Second, there was participation from incumbents outside the industry, but with experience in telecommunications, in semiconductors, or in the computer industry. Finally, there were new firms searching for new opportunities. These firms were generally highly innovative and founded by entrepreneurs who were either former academics or former employees in the LAN industry.

Second, entry was mainly driven by the evolution of the technology itself. This evolution opened up opportunities for establishing new firms in emerging new segments (Kenney and von Burg, 2000) near the technological frontier and/or away from incumbents (Fontana and Nesta, 2006), which led to the opening of two segments. The high-end segment included products that were characterized by high performance, targeted to customers with large networks. The low-end segment encompassed lower performance switches that were targeted to customers with small networks. Hence in the low-end segment, manufacturers competed mainly on price, whereas in the high-end segment, competition was mainly based on the constant search for technical excellence and increased performance.

Third, exit was the result of a severe process of selection. Indeed, market polarization led to consolidation and to an increase in the rate of exit. However, among the firms that exited the industry, the vast majority were new firms, which were ultimately acquired by incumbents. For many of the new firms the chances of turning a new venture into a large firm were very few. In many cases, new companies usually revolved around a single innovative product or technology. Acquisition usually entailed the purchase of the new firm in a stock swap, followed by integration of the product as well as the technology (Kenney and von Burg, 2000).

In this paper we take the quality of a firm as the distance of its product(s) from the technological frontier. Our empirical work is based on the exhaustive list of 536 switch products that were introduced by 121 companies. These firms were identified as active in the industry precisely for having introduced at least one switch in the LAN switch market.[3] For each new switch that was introduced we have information on its list price, its technical characteristics, and the date of market introduction. Data on technical characteristics and prices for switches, and also for hubs and routers, were obtained from an original dataset of 1,825 LAN products (536 switches, 535 hubs, and 754 routers) that were marketed between 1990 and 1999. This dataset was constructed using information from specialized trade journals (*Network World* and *Data Communications*), which periodically publish Buyers' Guides and details on new product introductions.

[3] Companies that failed to introduce a switch product are thus ignored.

The set of 121 companies forms the population of firms that were active in the LAN switch industry. For each firm in our dataset we have information on the date of entry into and the date of exit from the switch industry and the number of switches that were introduced. Information on the firms' entry and exit dates was gathered from a variety of sources, such as the D&B Million Dollar Database and Lexis-Nexis. Additional information on the firms' backgrounds and founders was gathered by searching publicly available databases that aggregate news and press releases, such as ABI-Inform, and annual reports gathered from the Thomson Research (Global Access) database. Information on the type of exit (i.e., whether a firm survived or exited either by acquisition or liquidation by the end of the period) was obtained from a review of announcements in the specialized trade press and information contained in the CORPTECH database.[4] After consolidation we have a sample of 121 firms that together marketed a total of 503 switch products, including 33 switches for which we lack some technical characteristics.

The rapid growth of the LAN switch industry in the 1990s gave rise to a large number of both entries and exits. Of the 121 companies that entered the industry, only 38 still existed in 2005; 15 had exited through liquidation (i.e., they failed) and 68 had been acquired by a third party.

**3.2 The Three Components of Observed Product Prices**

The goal of this section is to provide a measure of firm quality, price strategies, and firm reputation. We assume that firm quality is captured by the quality of its products and

[4] This information was double checked, with press communications released by manufacturers.

synthesized by the distance of its product(s) to the technological frontier. Our methodology is based on the decomposition of the observed price into three components: distance to technological frontier, firm reputation, and price strategies all being conditional on product characteristics. Table 1 provides the list of product characteristics together with their summary statistics.

[Table 1 about here.]

Our procedure follows Stavins (1995) and reduces the multi-attribute structure -- i.e., the technological characteristics -- to a single-dimensional measure of product quality. Assuming independence across product technical characteristics, we project them onto a linear scale as follows:

$$q_m = \sum_j \beta_j z_{jm} \quad (1)$$

Eq. 1 suggests that quality $q$ of model $m$ can be measured as the weighted sum of its characteristics. The weights $\beta_j$ represent the marginal value of characteristic $j$ that both consumers and producers place on the $j^{th}$ attribute. These weights are approximated by regressing observed prices (deflated to 1996 US dollars using the sector-specific deflator for telecommunication equipment provided by the US Department of Commerce, Bureau of Economic Analysis) on characteristics, as follows:

$$p_{mit} = \alpha + \sum_j \beta_j z_{jm} + \alpha_t + \varepsilon_{mit} \quad (2)$$

where $p_{mit}$ is the log is the observed price for model $m$ introduced in the market by firm $i$ at time $t$, $\alpha$ is a constant, and $\alpha_t$ is a time fixed effect. Table 2 provides the results from the hedonic regression. With almost 70% of the variance of prices explained, the overall fit is satisfactory although a substantial part of the observed prices (30%) is due to factors other than those introduced in the regression. This may in turn be due to omitted product attributes and pricing that reflects changes in demand.

[Table 2 about here.]

Whereas the observed prices embody measurement errors reflecting various factors such as changes in demand, promotional discounts and other non-quality components (Stavins, 1995), the predicted price $\hat{p}$ reflects (by construction) the quality $q$ of the product. Thus we posit:

$$q_{mit} = \hat{p}_{mit} \tag{3}$$

Eq. 3 states that ranking predicted prices is tantamount to ranking products according to their quality. However, in order to account more properly for product quality, we amend Eq. 2 in two ways. First in Eq. 2 the estimated weights are constrained to be constant over time, whereas the technology in the switch market is likely to have evolved over time. This suggests that, given significant changes in product quality in the 1990s, the pooled regression may produce inexact weights. Therefore, we interact all explanatory variables with annual dummy variables, in order to allow the weights $\beta_j$ to vary with time. Second we include a firm fixed effect $\mu_i$ to control for heterogeneity in the firms' pricing practices.

For example, positive values of $\mu_i$ can be interpreted as persistent (apparent) over-pricing: a firm mark-up beyond and above comparable values. The important point here is that values of $\mu_i$ provide information on the firms' pricing practices, not on product quality, which may be related to reputation, market power, and other unobserved persistent firm characteristics. Therefore, we amend Eq. 2 as follows:

$$p'_{mit} = \alpha + \sum_t \sum_j \beta_{tj}\left(z_{tjm} \times \alpha_t\right) + \alpha_t + \mu_t + \varepsilon_{mit} \quad (4)$$

Including the full vector of explanatory variables as specified in Eq. 4 yields an increased $R^2$ of 0.85, implying that accounting for changes in the marginal values of product characteristics and firm mark-ups explains a significant share of the variance of observed prices in the LAN switch market.

We use Eq. 4 to decompose the observed price into three components. The first component is based on product quality and is used to compute the firm's distance to the frontier. Amending Eq. 3 by subtracting $\mu_i$ from the predicted price $\hat{p}$ yields:

$$q'_{mit} = \hat{p}'_{mit} - \mu_i \quad (5)$$

We use estimated product quality $q'$ to compute distances of products from the frontier; that is, we rank products in a vertical product space. To do so, for every product we compute its distance to the frontier as follows:

$$d^f_{mit} = \max\left(q_t\right) - q'_{mit} \quad (6)$$

where $q'_{mit}$ is the quality of model *m* by firm *i* in year *t*. The higher is $d^f_{mit}$, the farther is the product from the frontier. Because firms can introduce several products in a given year, we retrieve for each multi-product company the minimum distance to technological frontier, that is, we compute DISTANCE TO FRONTIER as: $d^f_{it} = \min\left[d^f_{mit}\right]_{it}$.

The second component of the observed price is the firm fixed effect $\mu_i$. Indeed, a positive FIRM EFFECT is likely to reveal a persistent apparent overpricing strategy by firms, which may indicate market power, reputation, unmeasured quality attributes, and the like.[5] The last component of the observed price exploits the price residual of product *m* introduced by firm *i* at time *t*, $\varepsilon_{mit}$, as a measure of pricing strategy. Provided that all of the relevant quality attributes are accounted for by the explanatory variables, the residuals reveal which firms are offering apparent "bargains" (i.e., negative residuals) and which firms are offering apparently over-priced products (i.e., positive residuals). This makes a strong case for including the residuals among the explanatory variables in the duration analysis. For multi-product firms, we use the mean PRICE RESIDUAL: $\varepsilon_{it} = mean[e_{mit}]_{it}$.

All three components -- DISTANCE TO FRONTIER $d_{it}^{f}$, FIRM EFFECT $\mu_i$ and PRICE RESIDUAL $\varepsilon_{mit}$ -- are then included in the vector of explanatory variables for firm survival. Based on previous results (Fontana and Nesta, 2006), we assume a non linear relationship between product quality and survival, and we enter both DISTANCE TO FRONTIER and its squared value. Importantly, we do not have a strong prior belief as to whether to include or exclude higher order effects for other price components. A preliminary exploration of the data suggested that both DISTANCE TO FRONTIER $d_{it}^{f}$ and its squared

[5] Note that mono-product companies are not included in the vector of firm dummy variables. In this case, we do not estimate $\mu_i$ instead, we set it arbitrarily to 0. Of the 121 companies in our sample, this concerns 46 firms.

value should be used as explanatory variables, whereas higher order effects for other price components ($\mu_i$ and $\varepsilon_{mit}$) were not useful.

### 3.3 Control Variables

Recent studies have stressed that firm survival is also related to the mode of entry (Buenstorf, 2007; Thompson, 2005). We use information on founders' backgrounds and firms' main activities to assign to firms a status defining their mode of entry. We define SPIN-OUTS as those firms whose main line of business is the LAN industry. This includes cases where the founder(s) were already employed in the LAN industry in the year prior to the founding of the new company, and university spin-offs. We define DIVERSIFIERS as firms whose founder(s) had no prior experience in the LAN industry and whose main line of business was outside the LAN industry (i.e., computer, semiconductor, etc.) at the time of entry into the switch market.

We identify three possible fates for firms: Failure (i.e., liquidation), Buy-out (i.e., acquisition), and Survival. More than two thirds (69%) of the firms in our sample exited the LAN switch industry after entry. Spin-outs exit mostly as a result of acquisition. Among the survivors, Spin outs are the largest share of the total, although almost half of Diversifiers survive. This preliminary evidence suggests that, although firms with greater pre-entry experience constitute most of the survivors, those that exit generally tend to be bought-out. This indicates that their fate may be linked to their status and that exit should not be treated as a homogeneous event.

In addition to pre-entry experience, the literature on firm survival highlights that firm size and age are among the most important determinants of firm selection (Dunne, Roberts, and Samuelson, 1988; Mata and Portugal, 1994; Audretsch, 1997). The size variable (SIZE) is constructed as the logarithm of the total number of employees at the time of entry. We define AGE AT ENTRY as the number of years as of the time of entry into the switch market, since the firm's institutional birth.[6]

We also add R&D Intensity (R&D INTENSITY) as a measure of innovative capital. This variable is constructed as the share of R&D expenditures in total revenues, at the time of entry, and may be a proxy for knowledge capital at the time of entry, similar to Cockburn and Wagner (2007) patent stock measure.[7] Finally, to capture the effect of the industry's life cycle on firm survival (Klepper and Simmons, 2005), we add two industry level variables: ENTRY RATE and EXIT RATE are the number of new firms and the number of firms exiting the switch industry respectively. Both variables are lagged one year to avoid endogeneity biases.

[Table 3 about here.]

Summary descriptive statistics for these explanatory variables are reported in Table 3. In all regressions, we consider 121 firms, of which 83 eventually exit the industry. All firm

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[6] This is different from studies that use census data, in which the age of the firm is generally taken as the number of years of presence in the census (i.e., the dataset).

[7] It is important to note that after accounting for revealed firm quality through product differentiation, mode of entry, intangible capital and firm size, the variable AGE AT ENTRY captures two effects: (i) the combined influence of availability of financial resources and diversification in the firm's product portfolio; (ii) a residual unobserved heterogeneity effect, related essentially to the firm's past experience in doing business, implying that older firms are more able to survive in their economic environment.

level variables take values at the time when the firm enters the industry. All duration models include a full vector of entry-year dummy variables. Expanding the dataset by time intervals yields a total of 600 observations.

**3.4 Modelling Firm Survival**

We develop two sets of econometric models to evaluate the factors that affect the fate of innovative firms. First, we estimate a discrete time duration model to explain the probability of exit (Prentice and Gloeckler, 1978). Suppose there are firms $i = 1, \ldots ,N$, that enter the industry at time $t = 0$. The hazard rate function for firm $i$ at time $t$ and $t = 1,,T$ is assumed to take the proportional hazard form: $\theta_{it} = \theta_0(t) \cdot X'_{it}\beta$ , where $\theta_0(t)$ is the baseline hazard function and $X_{it}$ is a series of time-varying covariates summarizing observed differences among firms. The discrete time formulation of the hazard of exit for firm $i$ in time interval $t$ is given by a complementary log logistic function such as:

$$h_t(X_{it}) = 1 - \exp\{-\exp(X'_{it}\beta + \theta(t))\} \qquad (7)$$

where $\theta(t)$ is the baseline hazard function relating the hazard rate $h_t(X_{it})$ at the $t^{th}$ interval with the spell duration (Jenkins, 1995).

Second, we apply a competing risk model to account for heterogeneity in firm exit. In this second set of models, we relax the assumption of homogeneous exit by accounting for the mode of exit, namely firm liquidation, or firm acquisition. The extension of the standard pooled duration model to two exit forms is referred to as the Competing Risks Model (CRM) (Jenkins, 2004). The two destinations are treated as independent, so that the probability of exit by liquidation is assumed not to depend on the probability of exit by acquisition. In practical terms, the independent competing risk framework treats both exits as right censored (Lancaster, 1990; Jenkins, 2004) allowing the full set of parameters to vary according to the different destinations:

$$h_t\left(X_{ijt}\right)=1-\exp\left\{-\exp\left(X'_{it}\beta_j+\theta_j(t)\right)\right\} \tag{8}$$

where, in our case $j$ = 1 or 2 respectively, depending on the mode of exit (liquidation *versus* acquisition). We test whether these two forms of exit can in fact be treated as independent. This is equivalent to testing the null hypothesis of equality for all parameters. The test statistic is $2\left[\ln\left(L_{CR}\right)-\ln\left(L_{SR}\right)-\sum_j n_j \ln\left(p_j\right)\right]$, where $ln(L_{CR})$ is the maximized log-likelihood from the competing risk model (the sum of those from the component models), $ln(L_{SR})$ is the maximized log-likelihood from the single-risk model, $n_j$ is the number of exits to state $j$, and $p_j = n_j / \sum_j n_j$, where there are $j = 1, \ldots, j$ destination states. This test statistic is Chi-squared distributed with degrees of freedom equal to the number of restrictions. Additionally, we perform the Hausman test for independence of irrelevant alternatives test (IIA) to test whether each exit can be treated as independent from all other alternatives.

**4 The Determinants of Market Selection in the LAN Industry**

We start our empirical investigation by accounting for different types of exit: exit by liquidation, by acquisition (being acquired), or by either liquidation or acquisition. Table 4 reports the results.

[Table 4 about here.]

In Column (1), we account for exit by liquidation versus survival and acquisition. The striking result lies in the pronounced effect of distance to frontier on liquidation. The first order effect of DISTANCE TO FRONTIER is positive, indicating that firms capable of being close to the frontier have a relatively higher probability of surviving. However, the negative and significant coefficient of the squared value suggests that the relation is non-linear and that exits mainly occur among firms located in the middle of the market. We note a similar and significant - albeit less pronounced - effect of DISTANCE TO FRONTIER on the probability of being acquired (Column 2) and on the probability of liquidation or acquisition (Column 3).

The extrema are found at the 30th, 25th and the 26th percentiles for Column (1) to (3) respectively. This implies that for more than two thirds of the firms in the industry, competition based on quality - rather than price – will prove harmful. This suggests that competing in the high end of the market is a very risky strategy, for only a fraction of these companies will actually benefit from innovation. This is a good reflection of the situation in the switch market during the 1990s, which was polarized between high-end and low-end. At the high end of the market firms compete to be at the frontier and those that lag behind do not survive. At the low end competition occurs at the boundaries with the high-end of the market, where firms struggle to survive, while firms serving niches at the bottom of the low end have a higher probability of surviving.

The non-monotonicity of DISTANCE TO FRONTIER is puzzling. In the end, why don't medium-quality firms locate in the low-quality end of the market and outperform "low quality" firms? To answer this, one should take a broader look at the LAN industry, which also includes routers and hubs. Whereas routers are more technologically sophisticated than switches, hubs constitute products of lower technological quality that compete directly with low-quality switch products. Medium firms who are strong in the hub market do not enter because they do not want to cannibalize their own hub business. This, in turn, constitutes an incentive for firms to move up the quality ladder in the switch market, where indeed selection is fiercer.

It is worth noting that the other price components convey little information on firm liquidation. The price residual displays the expected sign in Column (1): firms with overpriced products are more likely to quit the scene. A significant and negative firm effect is observed on the probability of being acquired (Column 2). One plausible interpretation is that firms with high reputation and/or market power are more profitable and hence less exposed to acquisition. On the whole, these two components of observed prices seem to be only weakly connected with a firm's fate.

The remaining variables behave as expected: the variable SPIN-OUT enters negatively and significantly in all types of exit, indicating that firms with higher pre-entry experience have a relatively lower probability of exiting the switch industry by either liquidation or acquisition. For both cases, the marginal effect is quite large, since it corresponds to a reduction by a factor of 3 (Column 1) and 4 (Column 2) of the probability of exiting. R&D INTENSITY, SIZE, and AGE AT ENTRY are all significant determinants of the firm's fate. Notably, R&D INTENSITY enters with a significant negative sign in all types of exit, suggesting that possessing a higher stock of innovative capital reduces the probability of leaving the industry. AGE AT ENTRY indicates that older firms have a lower probability of leaving the industry by liquidation or being acquired.

Thus three important conclusions can be drawn: (i) the effect of product quality on firm survival is very large; (ii) the effect of product quality on firm survival is highly non linear, in line with the idea of a two-tier market structure where firms located in the middle of the market are the least likely to survive as free-standing enterprises; and (iii) there is only weak evidence of the role of the price residual and the firm effect on the firm's fate. Altogether the sample is behaving as expected and is robust to alternative specifications of the hazard rate function and to the inclusion of firms' unobserved heterogeneity.[8]

Still, the above results remain somewhat disappointing. Although the magnitudes of all variables are similar across types of exit, they do not reveal strong differences in the determinants of exit by liquidation and exit by acquisition. Moreover, they do not account for the fact that the sum of the probability of each type of exit, conditional on all right-hand-side variables, should add up to unity. In fact, one should analyze the relationship between firm strategic positioning and exit types simultaneously. We provide this type of analysis using a multinomial logistic competing risk model. Table 5 displays the results of the competing risk model. Column (4) reports the results of the comparisons between the alternatives of exiting by liquidation and surviving. Results of

[8] These results are robust to alternative specifications of the hazard rate function and to the inclusion of firm' unobserved heterogeneity. Moreover, the second-order polynomial of DISTANCE TO FRONTIER was tested against higher order polynomials. The results clearly indicate that the second-order polynomial is the most suited for the analysis. Lastly, we measured the distance to the frontier using observed prices and predicted price with firm fixed effects. The result suggests that with the exception of observed prices, which come out not significant, the direction of the relationship between distance-to-frontier and survival is robust across measures.

the comparison between exit by acquisition, and survival are reported in Column (5). Column (6) compares the two alternatives of exiting by acquisition and exiting by liquidation.

[Table 5 about here.]

Before we examine the results, it is important to test for the existence of significant differences in exit types. The Hausman test of independence of irrelevant alternatives implies that outcomes "liquidation" and "survival" (Column 4) and outcomes "acquisition" and "survival" (Column 5) are independent of the third alternatives. This reveals that all outcomes are independent of other alternatives and each binomial choice must be investigated for its own sake. Next, the LR test examines the null hypothesis that any pair of outcome categories can be combined, due to the lack of significance in parameter estimates (all estimates are nil). Clearly, the results are in line with the Hausman test, since for all alternatives being examined, we reject the null hypothesis that coefficients associated with a given pair of alternatives are 0.

As a consequence, there are significant differences in the factors that drive the various outcomes in general, and between liquidation and acquisition outcomes especially. Now looking at the parameter estimates in Column (4), DISTANCE TO FRONTIER has a positive and significant coefficient, suggesting that firms that are located relatively farther away from the technological frontier do in fact have a higher probability of exiting by liquidation than of surviving. The relationship is non-linear as indicated by the negative and significant coefficient of (DISTANCE TO FRONTIER)$^2$. The same applies to exit by acquisition (Column 5), although as reported in Table 5, the effect is less large. Choosing to locate in the middle of the quality scale is the most dangerous strategy for firms, while positioning at either end - near the frontier or far from the frontier - may be the right strategy to survive as a free-standing enterprise.

A striking result emerges from the negative significance of DISTANCE TO FRONTIER in Column (6). The negative parameter estimate suggests that firms that are located close to the frontier have a higher probability of being acquired than of exiting by liquidation. This is confirmed by the coefficient $(\text{DISTANCE TO FRONTIER})^2$, which is positive and indicates that the probability of being acquired is higher for firms that are located very close to the frontier, decreases as distance increases, and then increases again for those firms located farthest away. Overall, both of these results confirm that acquisitions are mainly triggered by the need to appropriate the technology of rival firms, enrich firm product portfolios, and improve research activities. The other price components are insignificant, although in Columns (4) and (5) they are consistent with Table 4 in their magnitude and significance. The important conclusion here is that pricing decisions by firms disclose different sorts of information about the companies. But of the three components that we have identified in this paper, only the firm's capacity to locate near the technological frontier plays a significant role in shaping the firm's fate.

Coefficients for AGE AT ENTRY and SIZE are all negative and significant (Columns 4 and 5), indicating that bigger firms, endowed with better availability of financial capital have a relatively higher probability of surviving. The coefficient of SPIN-OUT is also negative and significant, indicating that possessing pre-entry experience decreases the probability of exiting by liquidation rather than surviving. Finally, the direction of the effect of R&D intensity is as expected (i.e., positive on survival and negative on both acquisition and liquidation) and supports the general idea that a large stock of intangible capital is important for firm survival. Note that although not significant, firms with a larger R&D effort seem more attractive for acquisition relative to liquidation. However possessing a large stock of intangible capital also makes potential targets more expensive to purchase (Hall, Jaffe, and Trajtenberg, 2005). In a context where knowledge obsolescence is extremely rapid, this may in turn inhibit acquisitions.

Altogether, these estimates provide new results that enrich our analysis and shed some light on our initial hypotheses. When exit is treated as a homogeneous event, strategic product positioning is an important determinant of firm survival, in the sense that being located close to the frontier increases the probability of surviving. However, among exiting firms, those that are located close to the frontier are more likely to be acquired; thus, position relative to the technological frontier seems to act as a signal of firm quality.

Table 6 displays the predicted probability of each mode of exit.[9] We observe that for the median firm with average entry year and entry type, the overall liquidation rate is 5%, the probability of acquisition is 21% and the survival probability is 74%.[10] At first sight, the overall probability of exit, either by liquidation or by acquisition, seems low: the median firm has three chances out of four of surviving as a stand-alone firm.

[9] We first computed the predicted probability using the median values of the continuous variables (time, age, size, distance to frontier, R&D intensity) and the mean values of the dichotomous variables (entry-year dummy variables and entry type). All marginal effects were computed as discrete change, holding all other independent variables constant at their mean or median values.

[10] Note that the sum of the predicted probabilities equals unity.

Comparison of this result with the observed overall exit rate for the whole period 1990-2005 suggests the presence of large effects at the margin for each independent variable.

We therefore compute the marginal effects of all significant variables. We compute the discrete change in the predicted probability by imputing a variation of two quintiles around the median value of each continuous variable - i.e. from the 30th to the 70th percentile - holding all other variables constant. Because of the non-linearity of the effect of distance from the frontier on survival, we compute the change in the predicted probabilities while at the frontier, at the 30th and at the 50th percentiles. For the dichotomous variable SPIN-OUT, we computed the discrete change from being a diversifier to being a spin-out. All changes are reported as absolute and relative change in probability. We have two important observations:

[Table 6 about here.]

First, we observe that Age acts differentially on the mode of exit from the industry. Although the marginal effect of Age on survival confirms the role of post-entry experience, the mode of exit (acquisition versus liquidation) matters. Firms that exit as a result of liquidation have survived longer in the market than have firms that are acquired. Our interpretation is related to the presence of sunk costs and assumes that, on average, exit by acquisition has lower sunk exit costs than does exit by liquidation. Based on this interpretation, firms that are struggling in the market should always prefer to exit by acquisition than by liquidation. These firms would enter the mergers and acquisitions market, and offer their quality at a given price to potential buyers. In other words, they enter a market in which firms compete to be acquired, the choice of exit by liquidation being a last resort.

Second, the presence of a non-linear relationship between firm location (relative to the frontier) and survival hints at the possibility that there are some regions in the quality space where firms are more at risk. In particular, firms that are located at the 30$^{th}$ percentile have to cope with the highest probability of exiting by any mode, and of exiting through liquidation in particular. Firms that are located close to the frontier face an increasing probability of being acquired, since the risk of being acquired peaks at the 30th percentile. Thus, competition in the LAN industry is a race in which most players commit resources to innovate along the quality ladder. But only one firm will make it to the frontier, whereas others will innovate with products of substantial but lower quality. Our analysis reveals that these good, but not-good-enough innovators are more exposed to acquisition.

Our analysis has the following important implications. From the viewpoint of the literature on industrial dynamics, our results stress that firms with higher pre-entry experience are relatively more likely to be acquired, especially immediately after innovation has occurred. Recent studies have highlighted the importance of pre-entry experience for firm survival (Klepper, 2002; Thompson, 2005). Our study, however, provides insights that are relevant to highly innovative sectors.

Our analysis also has implications for the empirical literature on aggregate economic growth at the industry level (see Baily, Hulten, and Campbell, 1992; Haltiwanger, 1997; Baily, Bartelsman, and Haltiwanger, 2001, among others). These empirical analyses seek to decompose sectoral - or aggregate – economic growth into an internal firm effect (firms increase their own levels of productivity), an external effect (changes in market shares across incumbents), and a market selection effect (the impact of firm entry and exit on economic growth). In particular when entrants outperform exiting companies, market selection contributes positively to aggregate economic growth.[11] Because information on modes of exit is not readily available in large datasets, exit is treated as a homogeneous event, such that exit by acquisition equates with exit by liquidation. But since acquired companies are located closer to the frontier than are firms that exit by liquidation, the benefits of market selection may have been underestimated.

Finally, our analysis of innovativeness and mode of exit has also important policy implications. In dynamic industries, acquisitions are mainly finalized at strengthening market positions at the expenses of the closest competitors. Our results highlight that targeted firms are generally young and are endowed with experience that is inherited from skilled founders. This suggests that acquisitions are a means of acquiring knowledge and innovative assets that the buyers do not possess. Evaluating these implications in terms of welfare gains/losses from these mergers is not straightforward and beyond the scope of this paper. However, acquired assets are generally costly to replicate and require time to be developed. The occurrence of these mergers allows the existing resources to be kept within the economic system while at the same time avoiding duplication of costs. This is an important aspect that should be taken into

[11] With few exceptions (Nishimura, Nakajima, and Kiyota, 2005), the contribution of this market selection is generally positive. According to textbook economics, this is to be expected since it implies that only the most profitable companies stay in the industry.

consideration by antitrust authorities, which usually are more concerned with the anticompetitive effects of mergers and acquisitions.

## 5 Conclusion

This paper has investigated the relationship between product innovation and firm survival in a high-tech industry. First, we looked at the hazard rate of firms by considering exit as a homogeneous event. We found that firm quality, as captured by firm location with respect to the technological frontier, innovative capital, pre-entry experience, age, and size are important determinants of firm survival. Second we have extended the analysis to the case of heterogeneous exit. We found that, when controlling for firm level attributes, among firms that exited, those located close to the frontier were more likely to be acquired, suggesting that position with respect to the technological frontier acts as a signal of firm quality. We also found support for the presence of a positive relationship between the firm's R&D effort and the probability of surviving. However, in the event that the firm does exit, its R&D effort does not significantly influence whether it exits via liquidation or exits via acquisition.

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Table 1: Summary Statistics on the Technological Characteristics of the LAN Switch Products (N = 503)

| Variable | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|
| Constant Price | 38257.970 | 72790.430 | 402.178 | 522824 |
| Log of Price | 9.490 | 1.415 | 5.997 | 13.167 |
| Backplane Capacity | 7.168 | 1.808 | 2.398 | 13.236 |
| Number of Ethernet Ports | 2.061 | 1.643 | 0.000 | 6.645 |
| Number of Fast Ethernet Ports | 1.396 | 1.540 | 0.000 | 6.645 |
| Number of FDDI Ports | 0.268 | 0.732 | 0.000 | 4.575 |
| Number of Token Ring Ports | 0.260 | 0.912 | 0.000 | 5.820 |
| Number of 100VG-AnyLAN Ports | 0.044 | 0.307 | 0.000 | 4.174 |
| Number of ATM Ports | 0.730 | 1.285 | 0.000 | 5.198 |
| Number of Gigabit Ethernet Ports | 0.360 | 0.976 | 0.000 | 4.875 |
| VLANs Capability | 0.797 | 0.402 | 0.000 | 1.000 |
| Chassis | 0.268 | 0.444 | 0.000 | 1.000 |
| Fixed Configuration | 0.390 | 0.488 | 0.000 | 1.000 |

Table 2: OLS Regression on Observed Prices

| | |
|---|---|
| Backplane Capacity | 0.236 |
| | [0.036]*** |
| Number of Ethernet Ports | 0.09 |
| | [0.028]*** |
| Number of Fast Ethernet Ports | 0.04 |
| | [0.037] |
| Number of FDDI Ports | 0.024 |
| | [0.060] |
| Number of Token Ring Ports | 0.132 |
| | [0.046]*** |
| Number of 100VG-AnyLAN Ports | 0.248 |
| | [0.122]** |
| Number of ATM Ports | 0.112 |
| | [0.042]*** |
| Number of Gigabit Ethernet Ports | 0.361 |
| | [0.055]*** |
| VLANs Capability | 0.394 |
| | [0.099]*** |
| Chassis | 0.899 |
| | [0.130]*** |
| Fixed Configuration | -0.222 |
| | [0.088]** |
| Constant | 8.37 |
| | [0.389]*** |
| Observations | 503 |
| R-squared | 0.699 |

Dependent Variable: Deflated Product Price. Robust standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Year dummy variables omitted for clarity.

Table 3: Summary Statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Failure | 121 | 0.12 | 0.33 | 0.00 | 1.00 |
| Bought-Out | 121 | 0.56 | 0.50 | 0.00 | 1.00 |
| Survivor | 121 | 0.31 | 0.47 | 0.00 | 1.00 |
| Spin-Out | 121 | 0.83 | 0.37 | 0.00 | 1.00 |
| Diversifier | 121 | 0.17 | 0.37 | 0.00 | 1.00 |
| Age at Entry | 121 | 9.61 | 12.54 | 1.00 | 84.00 |
| Size (log) | 121 | 6.16 | 2.16 | 2.71 | 13.30 |
| Dist. Frontier | 121 | 2.42 | 1.09 | 0.00 | 4.69 |
| Price Residual ($\varepsilon_{it}$) | 121 | -.030 | .229 | -1.415 | 1.051 |
| Firm Effect ($\mu_i$) | 121 | -.310 | .668 | -2.913 | 2.077 |
| R&D Intensity | 121 | 0.11 | 0.20 | 0.00 | 0.70 |
| Entry Rate ($t-1$) | 600 | 1.23 | 2.00 | 0.00 | 6.80 |
| Exit Rate ($t-1$) | 600 | 0.44 | 0.58 | 0.00 | 2.00 |

Table 4: Firm Entry and the Hazard Rate of Exit in the LAN Switch Industry

| | Liquidation (1) | Acquisition (2) | Both (1) & (2) (3) |
|---|---|---|---|
| Time (Log) | -0.228 | -1.137 | -1.037 |
| | [0.378] | [0.286]*** | [0.254]*** |
| Age at Entry | -0.048 | -0.056 | -0.062 |
| | [0.019]** | [0.022]*** | [0.019]*** |
| Size (Log) | -0.175 | -0.319 | -0.275 |
| | [0.132] | [0.090]*** | [0.080]*** |
| Dist. Frontier | 4.109 | 1.346 | 1.549 |
| | [1.295]*** | [0.575]** | [0.555]*** |
| $(\text{Dist. Frontier})^2$ | -1.028 | -0.414 | -0.471 |
| | [0.314]*** | [0.146]*** | [0.141]*** |
| Price Residual ($\varepsilon_{it}$) | 1.433 | 0.109 | 0.015 |
| | [0.787]* | [0.532] | [0.474] |
| Firm Effect ($\mu_i$) | 0.182 | -0.453 | -0.406 |
| | [0.400] | [0.239]* | [0.228]* |
| R&D Intensity | -5.781 | -1.637 | -2.048 |
| | [2.398]** | [0.889]* | [0.845]** |
| Spin-Out | -1.171 | -1.405 | -1.474 |
| | [0.643]* | [0.523]*** | [0.467]*** |
| Entry Rate (Lagged) | -0.036 | -0.204 | -0.237 |
| | [0.171] | [0.126] | [0.121]** |
| Exit Rate (Lagged) | -0.074 | 0.066 | 0.104 |
| | [0.530] | [0.361] | [0.349] |
| Constant | -0.255 | 3.17 | 3.179 |
| | [1.901] | [1.122]*** | [1.041]*** |
| Number of firms | 121 | 121 | 121 |
| Number of firm exit | 15 | 68 | 83 |
| $P(Y \mid X) = 1$ | .021 | .062 | .082 |
| Log Likelihood | -97.031 | -170.486 | -195.218 |
| Chi-square | 44.2*** | 83.1*** | 91.9*** |

Number of observations: 600. Discrete Time Duration Model with Weibull Hazard Function. Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. All duration models include a full vector of entry-year dummy variables, not reported here for clarity.

Table 5: Competing Risk Model. The Determinants of the Exit Forms in the LAN Switch Industry

| | (4) | (5) | (6) |
|---|---|---|---|
| Time (Log) | -0.780 | -1.354 | -0.576 |
| | [0.462]* | [0.350]*** | [0.545] |
| Age at Entry | -0.076 | -0.075 | 0.000 |
| | [0.024]*** | [0.024]*** | [0.031] |
| Size (Log) | -0.418 | -0.451 | -0.033 |
| | [0.157]*** | [0.115]*** | [0.176] |
| Dist. Frontier | 4.894 | 1.962 | -2.931 |
| | [1.370]*** | [0.689]*** | [1.462]** |
| (Dist. Frontier) $^2$ | -1.213 | -0.571 | 0.642 |
| | [0.339]*** | [0.175]*** | [0.360]* |
| Price Residual ( $\varepsilon_{it}$ ) | 1.302 | 0.202 | -1.100 |
| | [0.835] | [0.614] | [0.957] |
| Firm Effect ( $\mu_i$ ) | 0.090 | -0.456 | -0.546 |
| | [0.424] | [0.279] | [0.464] |
| R&D Intensity | -6.366 | -2.522 | 3.844 |
| | [2.681]** | [1.034]** | [2.780] |
| Spin-Out | -2.337 | -2.108 | 0.230 |
| | [0.821]*** | [0.660]*** | [0.896] |
| Entry Rate ( $t-1$ ) | -0.291 | -0.257 | 0.034 |
| | [0.225] | [0.170] | [0.262] |
| Exit Rate ( $t-1$ ) | 0.224 | 0.077 | -0.147 |
| | [0.593] | [0.441] | [0.680] |
| Constant | 4.398 | 5.583 | 1.185 |
| | [2.341]* | [1.682]*** | [2.578] |
| Log Likelihood | -256.3 | | |
| Hausman Test (IAA) | 0.0 | 21.5 | |
| LR Test (Combined) | 57.9*** | 93.4*** | 28.2** |

Number of observations: 600. Competing Risk Duration Model. Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. All duration models include a full vector of entry-year dummy variables, not reported here for clarity.

(4) Liquidation vs. Survival

(5) Acquisition vs. Survival

(6) Acquisition vs. Failure

Table 6: Marginal Effects of Firm-Level Variables on the Mode of Exit

| | Liquidation | Acquisition | Surviving |
|---|---|---|---|
| Predicted Probability | 0.050 | 0.210 | 0.740 |
| *Time* | | | |
| Predicted at the $30^{th}$ percentile | 0.064 | 0.393 | 0.543 |
| Predicted at the $70^{th}$ percentile | 0.041 | 0.135 | 0.824 |
| Absolute Change | -0.023 | -0.258 | 0.281 |
| Relative Change | -35.9% | -65.6% | 51.7% |
| *Age at Entry* | | | |
| Predicted at the $30^{th}$ percentile | 0.063 | 0.259 | 0.678 |
| Predicted at the $70^{th}$ percentile | 0.036 | 0.148 | 0.817 |
| Absolute Change | -0.027 | -0.111 | 0.139 |
| Relative Change | -42.9% | -42.9% | 20.5% |
| *Size* | | | |
| Predicted at the $30^{th}$ percentile | 0.062 | 0.265 | 0.673 |
| Predicted at the $70^{th}$ percentile | 0.026 | 0.104 | 0.87 |
| Absolute Change | -0.036 | -0.161 | 0.197 |
| Relative Change | -58.1% | -60.8% | 29.3% |
| *Distance to Frontier* | | | |
| Predicted at the $1^{st}$ percentile | 0.001 | 0.077 | 0.922 |
| Predicted at the $30^{th}$ percentile | 0.056 | 0.279 | 0.665 |
| Predicted at the $50^{th}$ percentile | 0.040 | 0.212 | 0.748 |
| Absolute Change ($1^{st}$ vs $30^{th}$) | 0.065 | 0.175 | -0.240 |
| Relative Change ($1^{st}$ vs $30^{th}$) | $+\infty$ | 227.3% | -26.0% |
| *R&D Intensity* | | | |
| Predicted at the $30^{th}$ percentile | 0.063 | 0.224 | 0.713 |
| Predicted at the $70^{th}$ percentile | 0.038 | 0.192 | 0.77 |
| Absolute Change | -0.025 | -0.032 | 0.057 |
| Relative Change | -39.7% | -14.3% | 8.0% |
| *Spin-Out* | | | |
| Predicted for SPIN-OUT=0 | 0.15 | 0.517 | 0.333 |
| Predicted for SPIN-OUT=1 | 0.035 | 0.153 | 0.812 |
| Absolute Change | -0.115 | -0.364 | 0.479 |
| Relative Change | -76.7% | -70.4% | 143.8% |

The predicted probability has been computed using the *median* values of continuous variables (time, age, size, distance to frontier, R&D intensity) and the *mean* values of the dichotomous variables (entry-year dummy variables and entry type). All marginal effects have been computed as discrete change, while holding all other independent variables constant at their mean or median values.