Market Pioneering Capabilities and the Strategic Renewal of Organizations: Theory and Evidence

Ajay Bhaskarabhatla
Carnegie Mellon University

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Abstract

We document the process of strategic renewal of organizations through niche pioneering and new product development in a population of firms. Our main finding is that market pioneering capabilities routinized through product customization efforts lead to continued survival of firms in industries composed of niches. In addition, such capabilities shield firms operating in older technological trajectories from exit and help firms in newer technological trajectories expand. Our study, based on an unusually rich panel of the census of laser firms with self-reported measures of market pioneering capabilities, bridges the gap between inductive and large-scale studies of firms on the balance between strategies of leverage and change in high velocity markets.

Keywords: market pioneering, dynamic capabilities, ambidextrous organizations, preentry experience, best practices, laser industry

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1. Introduction

High-technology industries are increasingly seen to be composed of niches (or submarkets) and technological trajectories (or product generations) (Abernathy and Utterback 1978, Gort and Klepper 1982, Foster 1986, Christensen 1993, Klepper 1997, Sutton 1998, Agarwal and Gort 2002, Klepper and Thompson 2006). The strategic renewal of firms in such high velocity industries is an emerging research focus (Agarwal and Helfat 2009). The source of sustained success of firms in industries composed of niches is rooted in their ability to recognize market opportunities and renew their focus through pioneering activities (e.g., Teece Pisano and Shuen 1997, Helfat 1997, Leonard-Barton 1992). The ability to pioneer new niches is particularly important for firms operating in technological trajectories where new opportunities rarely arise, either because of the nature of the technology or because the technology is under the threat of obsolescence (e.g., Siggelkow and Levinthal 2003).

Central to our understanding of firm survival in such industries is investigating who gets to be the market pioneer, who survives in the face of change, and where do market pioneering capabilities come from? There are both macro evolutionary, ecological and micro organizational perspectives on these questions emphasizing the environmental factors and organizational capabilities respectively. Increasingly scholars have recognized that both macro and micro factors affect the evolution of market pioneering capabilities and firm survival.

Empirically, however, it is difficult to measure market pioneering ability, particularly in large scale studies of populations of firms in industries. Previous studies of firm survival in industry case studies measured firm capabilities more broadly using concepts such as preentry experience (Klepper and Simons 2000, King and Tucci 2002, Klepper and Sleeper 2005), timing of entry coupled with various mechanisms that confer advantages to early market entry (Leiberman 1988, Suarez and Lanzolla 2007), organizational learning and production experience (Argote 1999, March 1991), technological capabilities (Tushman and Anderson 1986), combinative capabilities

(Kogut and Zander 1992), and integrative capabilities (Helfat and Campo-Rembado 2009).

Combining the macro and micro perspectives on the determinants of firm survival, studies suggest that pioneering firms leverage their technological capabilities in newly created niches (e.g., Franco et al. 2009, de Figueiredo and Silverman 2007) or size and investment in R&D (e.g., Bhaskarabhatla and Klepper 2011). Although recent studies have recognized the interplay of the 'micro' organizational capabilities and 'macro' evolutionary industry dynamics in determining market pioneering and firm survival, they have largely addressed these dynamics *after* market entry based on the order of entry (e.g., Franco et al. 2009).

One explanation for the longevity of some firms in such segmented industries is that they enter new niches by chance and subsequently leverage their size and capabilities to their advantage. An alternative model of industry evolution contends that some firms are more likely to pioneer new market niches and hence survive longer even in the absence of any leverage to early entry. Consequently, the measurement of market pioneeing capabilities is central to testing these alternative perspectives (e.g., Eisenhardt and Martin 2000).

The dominant approach to measuring market pioneering beyond time of entry measures has been to study particular organizations and derive lessons through inductive case studies. This literature has attempted to open up the 'black box' of new product development by investigating the processes and factors that lead to the launching of successful products (Maritan 2007, Holmqvist 2004, Danneels 2002, Miner Bessoff and Moorman 2001, Brown and Eisenhardt 1995, Eisenhardt and Tabrizi 1995, Shoonhoven Eisenhardt Lyman 1990). For example, Brown and Eisenhardt 1997 identify organizational structures and processes related to continuous change and argue that firms improvise by engaging in several low-cost experiments to 'probe into the future.' The valuable insights gained from such case studies must be extended to large-scale empirical studies of breakthrough products.

The literature on organization theory also provides insights about the processes that facilitate market pioneering. The debate in this literature surrounds the role of mindful (managerial cognition) and less-mindful (routinized) activities on the

development of dynamic capabilities in organizations (Gavetti 2005). Levinthal and Rerup (2006) suggest that routine and mindful activities are complementary, particularly in contexts that require the monitoring of the environment, and recombination and improvisation of products. Case studies of new product development in particular organizations highlight the role of mundane activities but also suggest that such activities may be institutionalized with managerial action (Salvato 2009, Hargadon and Sutton 2000, Dougherty 1992, 1990).

In a similar vein, emerging research on ambidextrous organizations combines perspectives on organizational learning and argues that those firms that are good at balancing the exploration of new market opportunities and the exploitation of existing ones are more likely to succeed, particularly in fast paced environments (Knott 2002, O'Reilly and Tushman 2007).

The goal of this paper is to bring together these disparate perspectives in the management literature on organizational processes and market pioneering capabilities to explain firm survival. At a micro level, how do firms develop the capabilities necessary to develop new markets and what is the impact of institutionalized processes of new market development on firm survival? At a macro level, what is the impact of technological change on market pioneering and firm survival? In this study, we have the unusual opportunity to explore these questions empirically on a large population of laser firms.

We use a census of laser firms during the period 1997-2009 to test our hypotheses concerning market pioneering capabilities and firm survival. The data contain more than 80 different types of lasers in four broad technological trajectories, which in turn differ in their prospects for growth during the study period as they at different stages of the technology S-curve. Collectively, these laser firms service numerous independent niches (such as industrial, medical, scientific, military, and the like). We measure whether firms self-report on an annual basis as being able to develop custom versions of a particular laser and design and prototype a version of a particular laser for a novel use.

We follow multiple methods approach. We document using cases of firms and the history of the industry, the routines that firms use to develop new market opportunities that form the core of dynamic capabilities in such industries and their origins in the

industry. We also identify various technological trajectories in the industry based on our understanding of the technological history of the industry. We argue based on our qualitative study and empirical analyses that it is ambidexterity and dynamic market pioneering capabilities that allow firms to constantly renew and refresh and succeed on a sustained basis.

We find that it is the ability to actively seek opportunities to develop alternative, novel, and independent uses of the core technology that firms possess that determines continued firm success (Helfat and Raubitschek 2000). Surprisingly, many firms follow high-level routines in their search for new market opportunities. The persistence of such routines suggests the development of capabilities rather than *ad hoc* approach to problem solving (Winter, 2003), although prior managerial, market, or industry experience may lead them to institutionalize of such routines in the first place.

At its core, the paper relies on a simple variation of the theory of firm growth through the stochastic creation and destruction of submarkets proposed by Klepper and Thompson (2006). The theory is developed to portray a high velocity environment characterized by the stochastic arrival and destruction of market opportunities. According to the theory, firms are heterogeneous in their ability to pioneer new market niches which determines the number of independent submarkets they are actively participating at any moment in time and in turn their survival. The theory treats firms as homogeneous in terms of their exploitation capabilities. While the theory itself is silent about the origin of market pioneering capabilities and treats firm heterogeneity stylistically, our empirical context sheds new light on their origins. The theory predicts that firms with market pioneering capabilities (those that have institutionalized product customization routines) pioneer more submarkets and thus survive longer.

We find that the ability to develop custom lasers opens up new avenues for growth and contributes to firm survival more than any other factor including firm size (which correlated with firm age), incumbency, and vertical relationships along the production chain into various component markets. In the case of the laser industry, there is anecdotal evidence to suggest that such routines were developed by the earliest entrants to the industry in the 1960s when lasers were described as *a solution looking for a problem* and niche pioneering was critical for firm survival. The practices diffused across

cohorts of entrants to the industry. We speculate that the superior performance of laser intra-industry spinoffs can be explained by the inheritance of market pioneering abilities from parent firms.

The study contributes to the literature on dynamic capabilities by suggesting that the development of market pioneering capabilities are embedded in high-level routines of engaging with potential customers during the new product concept development phase. The study also contributes to the emerging literature on ambidextrous organizations by providing evidence to suggest that those firms that explore new market opportunities while exploiting existing ones survive longer. The study also contributes to the literature on strategic renewal of organizations, particularly in industries composed of submarkets. The study also informs the literature on organizational ecology and user-centered innovation by empirically examining a population of firms that constantly learn from lead users in the environment in contrast to the standard view of environmental determinism in organizational ecology.

The study provides prescriptions or *best practices* for managers. The study informs how firms and managers can institute high-level processes through mindful action internally for organizational renewal. Managers should look for alternative pioneering uses of their core technologies, particularly those that build on existing complementary assets, and co-opt communities of potential users during the product concept development phase itself. That persistent and routinized exploration can lead to sustained success is true not only for particular cases of organizations (Hargadon and Sutton 2000) but for a population of laser firms.

In the next section, the laser industry context is introduced. Subsequently, a theoretical model is developed and testable hypotheses are summarized. Empirical analyses and conclusions then follow.

2. The Laser Industry Context

The laser industry has been a preferred context to study the determinants of firm growth and survival in high velocity environments. The industry began in 1960 with the demonstration that various materials such as Ruby crystals and Helium Neon gas can lase to produce distinct colors of light with special applications. The industry continues to

renew itself with the discovery of numerous new wavelengths of light spanning gaseous, solidstate (crystal), semiconductor, and dye materials.

As shown in figure 1, these four material types form the four different technological trajectories in this industry, each of which prospered in different periods of the industry. The early period of the industry is dominated by gas lasers as reflected by the scale of newly discovered gas lasers. The extent of gas laser discovery subsided in the late 1970s as focus turned towards the discovery of solidstate crystal materials. The solidstate lasers have certain advantages over the older generation of lasers built based on gaseous lasing materials: solidstate lasers are less fragile, more compact, and efficient, particularly when newly emerging semiconductor lasers are used to stimulate solidstate lasers. The discovery of solidstate lasers peaked in the 1980s. A particular type of solidstate lasers pumped by diode lasers emerged as a broadly usable class of lasers since the late 1980s and competed with gas and dye lasers. Finally, semiconductor (or equivalently diode) lasers are beginning to emerge as a new generation of lasers. These technological changes

Besides these distinct technological trajectories, the laser industry also features independent submarkets or market niches. The characteristics of the light emitted by a laser define and limit its use (Klepper and Sleeper 2005). A red laser is used as a pointer but it cannot be used to weld materials while an infrared laser cannot be used as a laser pointer but can be used in a welding application. The two lasers operate in independent submarkets. Lasers based on different technological trajectories can, however, produce red lasers, i.e., a Helium Neon gas laser and a AlGaInP semiconductor laser both produce a red beam of light. Consequently, firms in the laser industry grew by developing new lasers and pioneering new uses for them, sometimes competing among technological trajectories.

The process of pioneering new applications for lasers began in the 1960s as lasers were labeled as *a solution looking for a problem*. Industry trade literature reports that laser firms pioneered new niches by established organizational units called ‘application laboratories’ or ‘system engineering groups’ (*Laser Focus* 1970, 1984). The leading laser firm established in 1966, *Coherent* pioneered various industrial uses of laser using its application lab, as documented by its system engineers (Saunders and Bellis 1980).

Bhaskarabhatla (2011) develops five cases of firms that entered after 1980 that suggest that pioneering firms in the laser industry maintained application labs and routinely prototyped laser based systems for new uses. Paschotta (2008, pp. 344) presents a similar view of the process of developing a novel laser.

We elaborate here on a sixth case of a firm founded in the 1990s to illustrate the process of pioneering new uses of lasers through customization that informs the subsequent theory development and empirical analyses:

Aculight, a laser firm founded by five laser engineers in 1993, developed custom lasers based on diode-pumped solidstate laser technology for niche markets in industrial, medical, and military domains. In one such effort, *Aculight* pioneered a laser-based hearing-aid. While traditional hearing aids involve the use of electrical signals to stimulate auditory nerves, laser-based hearing aids use optical signals. The principle was discovered in a university laboratory, which *Aculight* later designed and prototyped. The head of business development at *Aculight* explains,

> "They [Vanderbilt University] demonstrated the basic concept using a free-electron laser. You want a wavelength that is absorbed sufficiently to stimulate the nerve without ablating the tissue and it turns out that 1.85 μm is one of those wavelengths. The group approached *Aculight* to provide a portable light source. *Aculight* responded with an engineering prototype based on a diode laser array."

Like many laser firms, *Aculight* pioneered a new market for lasers but it did not get engaged in the development of a downstream medical device. Instead, *Aculight* strategically renewed its focus and explored other pioneering uses of auditory nerve stimulation using lasers such as treating balance disorders among elderly patients. The application involved placing a laser device in the ear, like in the hearing aid case, that stimulates a different part of the ear to help maintain balance. According to a company press release,

> "*Aculight* is pioneering [uses of] infrared neural stimulation. We first developed our *Capella* infrared nerve stimulator to enable and encourage research applications. We've also received an SBIR award to develop the first optical cochlear implant. Now we're working with two leading

vestibular groups to develop an optical vestibular implant. We believe that optical nerve stimulation could revolutionize treatment for many of the neurological disorders plaguing patients today."

The above case illustrates not only the process of pioneering new uses for a given laser type but also the renewal of product mix through the development of custom lasers for such uses. *Aculight* shows up in our dataset as a producer of Thulium lasers and custom medical systems for such applications as laser-based angioplasty.[1] The case developed here points to a high-level routinized process of new market development, which exists in some but not all firms in the industry.

As will be described momentarily, our data allow for measuring which firms had the capabilities to develop custom versions of lasers which in turn provides insights about market pioneering and firm survival. We investigate qualitatively the nature of firms that customize, design, and prototype lasers and find that among firms that have a record of custom laser development, many firms are founded by scientists with unparalleled technical capabilities in particular areas of specialization. For example, *Clark-MXR* pioneered several uses of Ti:Sapphire laser, *Access Laser Company* pioneered RF-excited CO2 lasers, *ADVEC* pioneered the uses of high-energy lasers, and *Cymer* pioneered uses of excimer lasers. Many firms with market pioneering capabilities are also spinoffs such as *DPSS Lasers* and *AraLight* which are known to have outperformed de novo entrants in the laser industry (Klepper and Sleeper 2005).

We further investigate the extent to which these firms with market pioneering capabilities applied for regulatory approvals for new laser-based medical devices. As shown in figure 2, the extent to which new laser-based medical devices are prototyped is consistent with the technological trajectories of various laser types. As shown in table 6, in the medical area firms with customization capabilities applied for approval of medical devices with some applying for as many as 38 experimental prototypes of laser devices.

Based on these technological, historical, and case study insights, we build a simple theoretical model to explain our results concerning market pioneering capabilities and firm survival.

[1] Aculight pioneered the use of thulium lasers, which provide greater surgical precision compared to holmium lasers (since it operates at 2.01 or 1.96 µm which is closer to 1.93 µm, the optimal wavelength for coronary angioplasty.)

3. Theoretical Framework and Hypotheses

The model is a simple variation of the stochastic model of entry, exit, and growth based on the creation and destruction of submarkets (Klepper and Thompson 2006).

An industry is composed of various submarkets. The industry begins at time $t = 0$ when its first submarket is created. Subsequently, submarkets are created according to a homogeneous Poisson point process with mean intensity λ. Each submarket has a random life, z, drawn from the distribution $H(z)$. Several results are derived assuming $H(z)$ is the exponential distribution, which implies a constant hazard of destruction of submarkets. There are two types of potential entrants, $C_h$and C_l corresponding to high ability and low ability firms. High-type firms have a probability of θ_h of entering a new submarket and the low-type firms have a probability of θ_l, where $\theta_h > \theta_l$. Upon entering, the firm's size in the submarket is drawn from the distribution $F(x)$, where F is continuous and strictly increasing. A firm's size remains constant for the duration of the submarket and then goes to zero as soon as the submarket is destroyed. Total firm size at any point in time is therefore the random sum of n draws from the distribution F, where n is the number of currently existing submarkets that the firm entered. Entry, exit, and firm growth are driven entirely by the random birth and death of submarkets. A number of results follow from this setup, which are elaborated in Bhaskarabhatla and Klepper (2011), but we focus here on one result of particular interest.

<u>Result 1:</u> At each age, high-type firms on average are active in more submarkets compared to low-type firms and high-type firms survive longer.

It follows from Klepper and Thompson (2006) that the number of active submarkets of firms of type $j = h, l$ at age s is Poisson distributed with mean $\theta_j\rho(s) = \theta_j\lambda\int_0^s[1 - \exp(z)]dz$. Since $\theta_h > \theta_l$, on average high-type firms enter more submarkets. The hazard of exit is strictly decreasing in the number of active submarkets. Hence, the high-type firms of a given age are active in more submarkets compared to the low-type firms. A firm exits the industry when it is down to its last submarket and that submarket gets destroyed in a given time period. The hazard of exit of a firm is declining in the

number of submarkets it is active in at the start of a period. Hence high-type firms survive longer than low-type firms.

The model is agnostic about the nature of strategic interactions among firms within submarkets and predicts that firms that can pioneer new niches are assured of continued survival. The previous literature on market pioneering has focused on post-entry dynamics that confer benefits to early entrants. In contrast, in this model all firms enter and exit a submarket at the same time which coincides with the creation and destruction of the submarket. While post-entry dynamics within each submarket are important, in high-velocity environments the arrival and destruction of market opportunities alone can explain many observed market outcomes. In other words, firms' success in such a context depends on change rather than leverage.

In exploration-exploitation terminology, firms are assumed to have homogeneous exploitation capabilities but differ in the extent to which they engage in exploration conditioned by their capabilities. In our model firm type determines the number of independent niches a firm enters and consequently firm survival. While the model treats firms as being born with market pioneering capabilities, others have relaxed these assumptions to obtain similar results (Mostafa 2009). The above simple model leads to the following hypotheses:

Hypothesis 1. Firms with market pioneering capabilities are present in more submarkets.

According to the model, the high type firms have a greater probability of θ_h of entering any newly created market niche. A higher θ_h corresponds to a greater degree of market pioneering capabilities. Such firms are more likely to be successful in entering newly created submarkets.

The hypothesis stated above is conceptually similar to the propositions developed in Helfat and Raubitschek (2000) which state that core knowledge, which is often scientific or technical in nature, forms the basis for multiple products within and across vertical chains of a firm and that such core knowledge combined with the ability to coordinate activities can lead to new product development. The core knowledge required to manufacture any type of laser is highly scientific and a laser can be customized, designed, and prototyped for several novel and independent uses allowing for horizontal product expansion paths.

Hypothesis 2. Firms with market pioneering capabilities survive longer

Since firms with market pioneering capabilities are more likely to be in more submarkets, they are also more likely to survive longer.

Hypothesis 3. Controlling for firm capabilities, the number of submarkets a firm is active in no longer explains firm survival.

According to the model, firm type (firm capabilities) determines the number of submarkets a firm enters on average and consequently its survival. Hence, controlling for firm type (that is, market pioneering capabilities), the number of submarkets no longer explains firm survival.

Although the model treats firm type as fixed and it is difficult to measure firm type directly, firms can institutionalize processes that build market pioneering capabilities dynamically, which we measure empirically. We treat market pioneering capabilities as a proxy for firm type and test these hypotheses using the laser industry data.

Hypothesis 4. Firms with market pioneering capabilities survive longer in technological trajectories threatened by obsolescence.

In technological trajectories where the rate of arrival of new submarkets is lower, firms with the ability to successfully enter new submarkets are shielded from competition from firms operating in emerging technological trajectories.

4. Data and Methodology

4.1 Empirical Context

The laser industry is a preferred context to study test the implications of our model as it features technological trajectories and niches. Previous studies of the laser industry evolution were based on the data collected from *Laser Focus* buyers' guides (Klepper and Sleeper 2005, Klepper and Thompson 2006, Bhaskarabhatla and Klepper 2011, and Bhaskarabhatla 2011) and focused on the U.S. laser industry. The data contained the timing of entry and the range of independent niches firms serviced on an annual basis, but not surprisingly explicit measures of firm capabilities did not exist.

We obtained from an alternative buyers' guide called *Photonics Spectra* for several reasons. First, since the mid-1990s, *Photonics Spectra* began to be published

electronically on compact disks, which allowed for the compilation of data across several product categories along the vertical chain (e.g., lasers, systems, and 12 other components categories such as electronics, optics, materials, etc.) in the industry and not just lasers. As a result, we have an unusually rich portrait of the various products each laser firms produced on an annual basis. Compiling such information using the *Laser Focus* buyers' guides is prohibitively expensive.

Second, *Photonics Spectra* measured market pioneering capabilities explicitly in its annual survey of firms. Shown in figure 2, the original questionnaire that *Photonics Spectra* uses for its annual survey of manufacturers in the laser industry requires firms to identify the particular type of product they manufacture and if they produce standard versions of the product and if they can customize, design, or prototype a product in that category. According to the survey questionnaire, firms are expected to support their claims in product listings with product literature and the claims are reviewed by the editorial staff at *Photonics Spectra* before publication.[2]

The survey also allows for the creation of new product categories. As new materials are discovered and new lasers are designed, custom applications for lasers emerge initially which later become standard applications (Bhaskarabhatla 2011). The buyers' guide captures this essential feature in the laser industry. As shown in figure 2, quantum cascade lasers, a type of semiconductor lasers are newly discovered and added to the questionnaire and marked by an asterisk. The firm shown in figure 2 designs and prototypes Q-Switched lasers, produces both stock and custom versions of the newly discovered quantum cascade lasers, and produces only custom versions of ruby crystal lasers.

Finally, *Photonics Spectra* contains information about advertising, foreign firms, number of employees, the size of the manufacturing facilities, and other information about the background of the firms, which is difficult to collect for a population of firms. In addition, since 2009 Photonics Spectra began collecting information on the ownership of firms (public vs. private) and the range of downstream industries firms serve. More than 90% of the firms in the dataset are privately owned and while their financial

[2] The publishers of *Photonics Spectra* note that they review the claims given that they publish only one annual buyers' guide and no monthly industry trade magazines.

information is difficult to obtain most studies based on easily available databases such as Compustat do not even measure the extent of firm entry in these evolving industries. Even the quinquennial U.S. Census Bureau data fails to capture such firms, particularly if they are short-lived for zero to four years.

Our dataset is based on this unusually rich 13-year panel of respondents to *Photonics Spectra* questionnaire during 1997-2009 that spans 14 broad and 1,705 narrow product categories produced by 8,970 domestic and international firms. In this study, we focus on a subset of 1108 firms that produced lasers but use the entire dataset to identify which laser firms also produced laser-based systems, and twelve other components contemporaneously. Each firm-year-product observation further contains information about whether the firm can produce the standard or custom version of the product, whether it can design and prototype new variants of the product or if it is a distributor or a service and repair firm, as shown in figure 2.

4.2. Variables

Firm Survival. The dependent variable in our study, firm survival is computed as a dummy variable that takes a value of 1 if a firm survived to the following year and zero otherwise. Given the large number of firms in our dataset, systematic information on exits by acquisitions is not available and exits by acquisition are not censored. However, if exits by acquisition are censored, we expect that the direction in which results change further supports our claims as it is evident from the history of the industry and prior work by Sleeper (1998) and Bhaskarabhatla (2011) that small pioneering firms, such as *Aculight* described earlier are more likely to be acquired.

In some regressions of firm survival, firm hazard of exit is the dependent variable. It takes the value zero if a firm survived to the following year and one otherwise. In both cases of dependent variable, exits in 2009, the last year in the dataset, are censored.

Market Pioneering Capabilities. Our market pioneering capabilities measure is self-reported by the firm. If a firm reports that it *can* develop customized versions of a laser for pioneering uses, the variable takes a value of 1 and zero otherwise in a given year. Time invariant measures of market pioneering capabilities are constructed based on the values during the year of firm entry (into our dataset). In other words, time invariant

measures take the value 1 if a firm reports that it can produce a custom version of a laser in its first year and remains 1 for the rest of the firm's tenure.

Measures of Technological Trajectories. Our technological trajectories measures are based on the broad category of lasers – gas, solidstate, semiconductor, and dye. The variable *Gas* takes a value 1 if a firm produces a gas laser in a year and zero otherwise. Similarly, dummy variables for *Solidstate*, *Semiconductor*, and *Dye* are defined.

Submarkets. We measure the number of submarkets a firm is active in by counting the number of different types of lasers a firm produces in a given year. The underlying assumption is that each type of laser supports a different application. Admittedly, each laser type contains many independent submarkets. For instance, a carbon dioxide laser can be used for several independent uses such as welding metals and surgical applications. While niches are conceptual constructs, their accurate measurement is challenging. Our measure of submarkets the best measure we can construct based on the entire range of activities by these firms.

Control Variables. Several firm-level variables are included as controls. Since our data begins from 1997 while the industry began in 1960, we do not have measures of firm tenure in the industry. While we know the year each firm is established, our data contains 1,705 different products and the year of establishment is not necessarily into lasers. However, since the data are a census of firms, we construct a measure *Incumbent97* which takes a value 1 if a firm entered prior to 1997 and zero otherwise. We also control firm size as measured by the number of employees to control for size and age effects. We also control for firm quality by including a variable *Advertiser* which takes a value 1 if a firm advertises in a given year and zero otherwise.[3] We control for foreign firms by including a dummy variable for firms originating outside the US. Foreign firms might be at a disadvantage as they away from the technological frontier being defined in the US. Consequently, foreign firms are expected to less able to exploit new market opportunities in comparison with the US-based firms. Some firms are merely distributors of lasers rather than manufacturers in some laser types. We control for such firms by including a variable for the number of different submarkets where the firm is a distributor. In

[3] Like in many industry directories, products of various firms in the industry are listed for free but some firms pay a small amount of advertising fee to highlight their product listings in the buyers' guides. Our measure of advertising is derived from these data.

addition, we also control for vertical relationships firms have into thirteen other product markets such as laser-based systems. Since we cannot control for every conceivable factor, we will allow for unobserved heterogeneity in some regression models as robustness checks of our results.

4.3 Descriptive Analyses

The number of laser firms annually has remained steady at an average of 384, but it masks considerable firm turnover. On average 13% of the firms exited annually and new ones entered the industry. The number of firms includes manufacturers, distributors, service firms, and firms that possess capabilities to customize, design, and prototype new laser products both in the US and internationally. Among the population of laser firms, a third of the firms report having customization capabilities and 13% of the firms report having the ability to design and prototype annually. The same type of lasers is more likely to be customized as well as designed and prototyped with diode-pumped solidstate lasers leading the table.

There are 82 different types of lasers including various gas, semiconductor, solidstate crystal, and dye lasers. Different lasers are based on different materials, which limit their use to particular niches. Even within a particular material-based laser, differences in continuous or pulsed laser beam, output power, and other characteristics can lead to further independent market niches.

The measures of product design capabilities allow us to investigate descriptively which type of -- gas, solidstate crystal, semiconductor, other -- lasers are more likely to be custom-produced. Table 1 contains the top 10 types of lasers that are frequently customized. They are also the most frequently designed and prototyped types of lasers. At the top of the list of frequently customized lasers are diode-pumped solidstate lasers. Bhaskarabhatla and Klepper (2011) argue that diode-pumped solidstate lasers, a category of highly efficient solidstate lasers customizable to many uses began to supplant other types of lasers in the 1990s in some niches while creating new niches. Gas lasers based on CO2 material are also among the most commonly customized lasers reflecting that new niches are pioneered most frequently in both new and emerging technological trajectories.

Table 7 provides descriptive statistics and correlations for all the variables used in regression analyses are listed in table 8.

4.3 Estimation

We use Pooled OLS to test whether market pioneering capabilities are associated with a larger number of submarkets, which is our hypothesis 1.[4] The results are robust to alternative specifications with fixed and random effects. Then, we use hazard/survival rate methodology to test remaining hypotheses relating to the probability of surviving in a given year. Following Franco et al. (2009) we use firm-year observation structure with a complementary log-log specification for our survival data. Furthermore, we control for firm-level unobserved heterogeneity by using random-effects specification. The results are robust to alternative specifications such as Cox proportional hazard models and hazard models with distributional assumptions about the hazard function such as the exponential distribution. The results are also robust to hazard models that accommodate unobserved heterogeneity. These models are also known as frailty models and they are random effects models for time-to-event data, where the random effect (frailty) has a multiplicative effect on the baseline hazard (Wienke 2011).

Since our data is a census of firms in the industry, selection bias is not a concern. Our measure of pioneering capabilities is not necessarily endogenous in the sense that large firms are not necessarily more likely to customize their lasers. It is the firms with institutionalized processes to pioneer more submarkets that enter more submarkets and survive longer. Empirically, the variables *pioneering capabilities* and *survival* are weakly correlated. However, we test for endogeneity by including time invariant measures of market pioneering capabilities. The results are robust to such alternative specifications.

5. Results

First, we establish that firms that possess market pioneering capabilities are more likely to be in a greater number of submarkets. The dependent variable for this analysis is

[4] Denrell (2003) notes that survivor bias can lead to compelling but potentially misleading evidence in support of some managerial or organizational practices. We however show that market pioneering capabilities are associated with more number of submarkets. We will also show that those firms that reported customization abilities also apply for regulatory approvals for newly created laser-based medical devices.

the number of submarkets a firm is servicing in a given year. The key independent variable is a dummy variable which takes the value 1 if a firm reports that it can develop customized versions of any of its lasers in a given year and zero otherwise.

In table 2 we provide the results of this analysis. Firms that advertise are in more submarkets as reflected by the positive and significant coefficient estimate of *Advertiser*. Similarly larger firms are also more likely to be more submarkets as reflected by the positive and significant coefficient estimate of *log(Employees)*. Firms originating outside the US and incumbents in the industry in 1997 are not likely to be in more submarkets than domestic firms and later entrants as coefficient estimates of *Incumbent in 1997* and *Foreign Firm* are not significant. Consistent with our model, firms that possess market pioneering capabilities are more likely to be in more submarkets as reflected by the positive and significant coefficient estimate. The results are robust to alternative specifications with fixed and random effects.

We test if firms servicing more submarkets survive longer and if market pioneering capabilities mediate the effect of scope on survival. In table 3 we provide the results of survival regressions. The coefficient estimate of *No. of Laser Submarkets* in specification (1) is positive and significant at the 0.01 level. The more types of lasers a firm produces in a given year the higher the likelihood of survival, consistent with the model. According to specification (2) controlling for the number of submarkets and other control variables, the more the number of submarkets where firms can develop custom lasers for pioneering uses the higher the likelihood of survival. The coefficient estimate of *No. of Laser Submarkets* is no longer significant, consistent with our model. The coefficient estimate of *Incumbent in 1997* is negative and not significant reflecting that early entry into the laser industry did not necessarily provide survival advantage. In specification (3) measures concerning the various technological trajectories are included. Except for the production of *Dye* lasers, production of *Gas*, *Diode* and *Solidstate* lasers is associated with higher likelihood of survival as reflected by the positive and significant coefficient estimates of these variables.

The results remain similar with the inclusion of control variables in specification (4). Market pioneering capabilities in each of these technological trajectories are included in specification (5). The positive and significant coefficient estimates of *Diode* and

Solidstate indicate that producing lasers of newer and emerging technological trajectories is associated with a greater likelihood of survival while producing lasers in older technological trajectories such as *Gas* and *Dye* is not. In addition, the coefficient estimate of *Pioneering Capabilities in Solidstate* is positive and significant indicating that the ability to create new uses of solidstate lasers is associated with a greater likelihood of survival. While producing gas lasers does not increase the likelihood of survival, the ability to produce custom gas lasers for new uses does increase the likelihood of survival. In specification (6) the results are robust to the inclusion of several variables measuring vertical integration into various component and system markets.

In table 4 we use time invariant measures of market pioneering capabilities as a robustness check for endogeneity of market pioneering capabilities. The results are broadly similar with those presented in table 3. The coefficient estimate of *Market Pioneering Capabilities in Solidstate* is positive and significant consistent with our theory that such capabilities help firms in older technological trajectories escape competition. However, our hypothesis also implies that market pioneering capabilities are important in gas and dye laser categories but it is not supported in these specifications.

Table 5 contains results of several specifications of semi-parametric and parametric hazard rate models as additional robustness checks. The dependent variable is the hazard rate of exiting the production of lasers. In these models a negative sign on the coefficient estimates corresponds to a lower hazard of exit (and longer survival). The independent variables are as described earlier for the survival regressions. The results of Cox proportional hazard regression are shown in specification (1). Consistent with the theory, market pioneering capabilities lower the hazard of exit not only in solidstate but also in gas and dye laser categories, all of which represent the older technological trajectories. In specification (2) exponential hazard function is assumed and the results are identical to those obtained in specification (1). Models (3) and (6) represent random effects specifications with Gamma and inverse Gaussian distributions for multiplicative unobserved heterogeneity and models (5) and (6) also accommodate for shared frailty at the firm level. The results are consistent with our hypotheses.

In specifications (3) and (4) we find support for our hypotheses, particularly that market pioneering capabilities are associated with a lower hazard of exit in gas (p-value

of 0.05) and dye (p-value of 0.1) technological trajectories in addition to solidstate. Overall our results are robust to a number of alternative specifications of firm survival models.

6. Discussion

We study the market pioneering abilities of a population of firms in a high velocity industry and find that such abilities along with their technological trajectories are an important determinant of firm survival. The effect of firm scope or the number of different niches a firm services disappears when market pioneering capabilities are controlled for (e.g., Cottrell and Nault 2004). Similarly, the effect of earlier entry into the industry and related legacy-based advantages derived from size and the effects of vertical relationships into various component markets are relatively insignificant determinants of firm survival compared to market pioneering abilities.

While preentry experience and post-pioneering market dynamics are important, an understanding of the processes that lead to successful market pioneering is essential to develop prescriptive lessons for managers. We documented how such processes conditioned the survival of firms in older and newer technological trajectories.

The study bridges the economics-oriented tradition in innovation with its focus on the evolution of technologies over time (Nelson and Winter 1982) and the organizations-oriented tradition that focuses on the actual product development process (Brown and Eisenhardt 1995) by documenting common innovation routines among some firms in an industry and their impact on firm survival. The study documents the approach of institutionalized problem solving to develop new products as a capability in laser firms over time, which gives rise to longer firm survival. While previous large scale studies of new product development focused on new models of existing products and compression of various stages of the process (e.g., Clark et al. 1987; Clark Fujimoto 1991; Hayes Wheelwright Clark 1988), we focus on breakthrough products that involves a balancing act between what is technologically and organizationally feasible and what the market demands.

The vast literature on user-centered innovation has emphasized the role of lead users (von Hippel 1988). Consistent with this literature, we find that firms that draw

inputs from customers with specialized needs during the early phases of product development process are more successful, particularly given the general purpose nature of the laser technology. The literature on organizational learning has emphasized the role of exploration and exploitation (Levinthal March 1993, March 1991, Ahuja Katila 2002). Consistent with this literature, we find that those firms that are ambidextrous and exploit existing submarkets but also look to customize their products in search of new submarkets do well (Tushman and O'Reilly 1996, Brown and Eisenhardt 1997, Benner and Tushman 2002, Gibson and Birkinshaw 2004, He and Wong 2004). We find that ambidexterity manifested as routines at the organizational level. Our study is unusual in that such longitudinal studies of ambidexterity are scarce (Raisch 2009).

The prevailing perspective from organizational ecology studies is that organizations are inert and they do not adapt to environmental changes (Amburgey, Kelly & Barnett, 1993; Audia, Locke & Smith, 2000; Hannan & Carroll, 1992). O'Reilly and Tushman (2007) note that ambidexterity is a dynamic capability and it can explain firm survival in the face of change. Our study of a population of firms supports this later view by identifying firms that do have ambidextrous capabilities to explore and learn from the environment while also undertaking exploitation strategy, and find that such firms survive longer.

The ability to routinely monitor the environment for new market opportunities also allows firms to selectively choose the new niches to enter in which they possess complementary capabilities (Taylor and Helfat 2009). While we do not measure complementary assets of firms and the degree of experimentation in their exploration, we do find anecdotal evidence for firms pioneering several uses of one particular laser type (such as a CO2 laser, a Sapphire laser, or a diode-pumped solidstate laser). In addition, there is evidence to suggest that the search process is persistent for three-fourths of the firm-laser combinations over time, in contrast to Nickerson and Zenger (2002) who suggest vacillation between exploration and exploitation as a strategy for success.

We extend the view of dynamic capabilities as identifiable and specific processes and the view that firms with such capabilities often use partial implementation of new products (e.g., custom prototypes) to gain new knowledge quickly (Eisenhardt and Martin 2000). While large firms are observed to find market pioneering disruptive and difficult

(e.g., Dougherty and Heller 1994), persistent search processes seemed to have allowed some of the oldest laser firms such as *Coherent* to navigate multiple technological trajectories as in other cases studies of firms in high velocity markets (e.g., Rindova and Kotha 2003).

Scholars have long recognized the importance of organizational processes (e.g., Eisenhardt and Martin 2000, Maritan 2007) but often data limitations prevented systematic large-scale studies of the impact of such processes on firm performance. Our study has attempted to overcome such limitations in one industry to highlight the importance of the processes to pioneer new niches for firm survival. Previous studies have contrasted the punctuated equilibrium view of industry evolution with the view of continuous and relentless change in organizations (Brown and Eisenhardt 1997). However, the case of the laser industry shows that while technological discontinuities can bring about rapid changes in the fortunes of firms and cause shakeouts (Bhaskarabhatla and Klepper 2011), those firms that routinize organizational processes to deal with change do better than others.

Anecdotal evidence and interviews with industry leaders suggests that the institutionalizing of customization, design, and prototyping practices emerged in the early 1960s and diffused to later cohorts of entrants to the laser industry. We know little about such a diffusion process. One question is whether intra-industry spinoffs from successful parent firms within the laser industry were more likely to inherit market pioneering abilities than *de novo* entrants. To what extent does employee mobility contribute to the diffusion of such capabilities or organizational routines and processes to be precise? We plan to address these questions in our future work.

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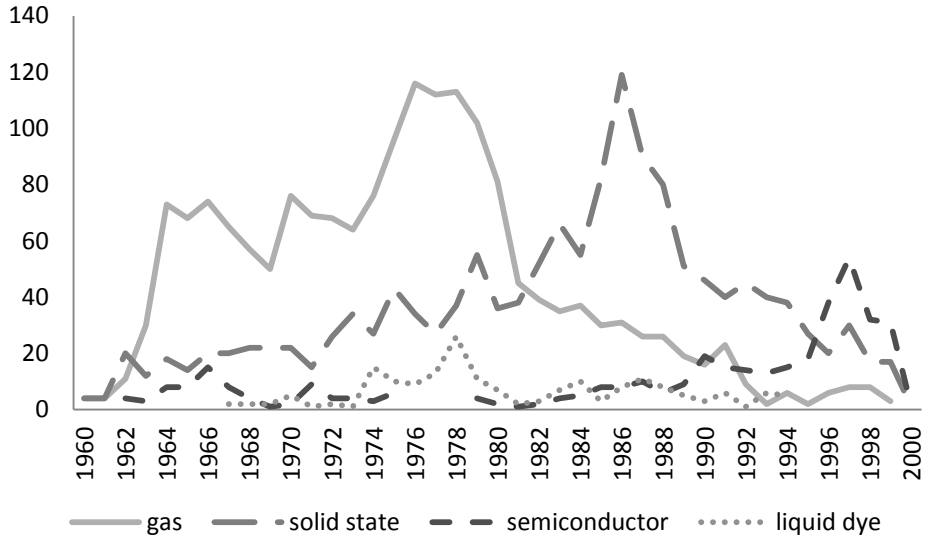
TABLES AND FIGURES

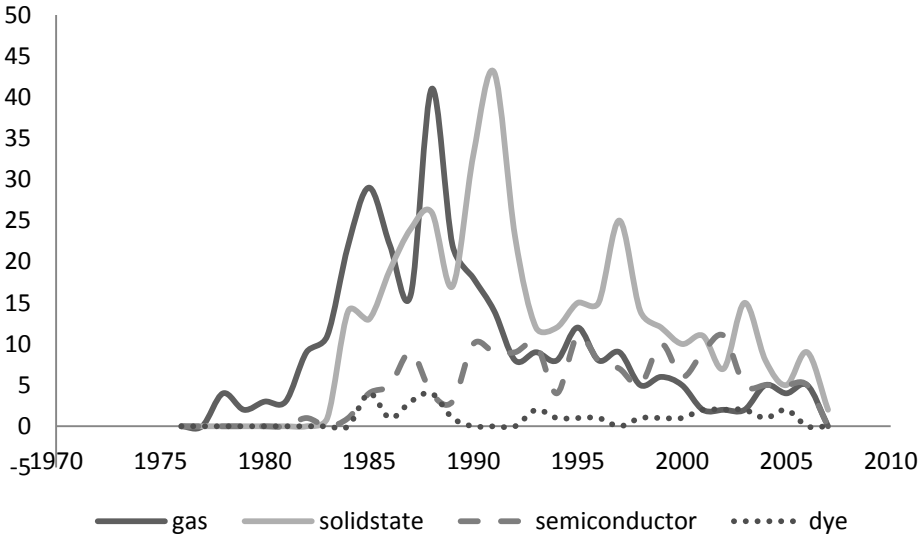
Figure 1. Newly discovered lasers as compiled by the author based on Koechner (2001) by technological trajectory. Source: Author's Calculations



Note: Figure 1 is constructed based on the list of references in Koechner (2001), which compiled the literature (both scientific and corporate) that reported the discovery of new lasers. For instance, ruby crystal and hene gas lasers were discovered in 1960, CO2 gas lasers in 1964, ion gas lasers in 1966, excimer gas lasers in 1975, vanadate lasers in the

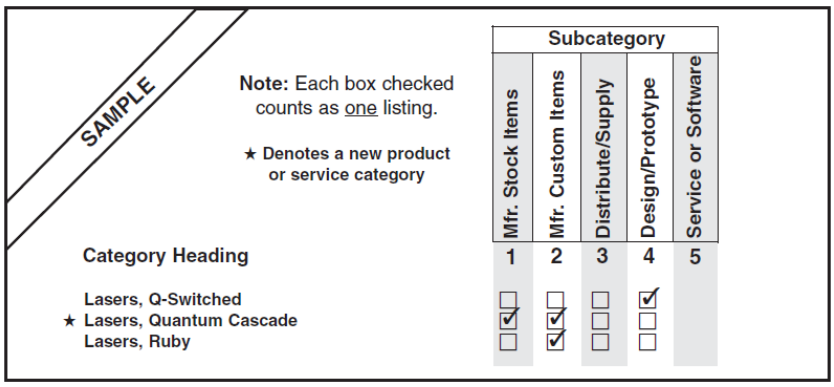
early 1990s and so on. On average more than 100 publications reported new gas lasers annually. The graph provides a unique window into the evolution of various technological trajectories in the laser industry.

Figure 2. Newly prototyped medical laser devices filed for regulatory approval at the US Food and Drug Administration by technological trajectory. Source: Author's Calculations



Note: The figure is based on 877 premarket approvals of prototype laser-based medical devices filed by US firms. For example, submissions for gas laser-based devices peaked in 1988 at 41 while those for solidstate lasers peaked in 1991 at 43. The trends in figures 1 and 2 are consistent by the type of technological trajectory.

Figure 3. Sample Questionnaire of Photonics Spectra Buyers' guide



Note: The figure is a snippet from *Photonics Spectra's* questionnaire. A firm reports whether it produces Q-Swtiched lasers, and if so, if it produces stock items, custom items, distributes, designs and prototypes, and / or provides other services (e.g. repair). The category, 'Lasers, Quantum Cascade' is marked by an asterisk as it is a newly created laser category.

Table 1. Top laser types by customization frequency

Laser Material	*Laser Type*	*Frequency of Customization*	*Frequency of Design, Prototype*
Lasers, Diode-pumped Solidstate	Solidstate	463	177
Lasers, Nd:YAG	Solidstate	437	138
Lasers, Diode	Diode	363	119
Lasers, Q-switched	Solidstate, Gas, Dye	198	66
Lasers, CO2 CW	Gas	157	59
Lasers, Nd:YVO4	Solidstate	152	42
Lasers, Ti:Sapphire	Solidstate	152	50
Lasers, CO2 Pulsed	Gas	141	78
Lasers, Ultrafast Pulsed	Solidstate, Diode	141	31
Lasers, Nd:YLF	Solidstate	134	38

Note: Diode-pumped solidstate lasers are most frequently customized and also designed and prototyped for new applications. Some types of semiconductor, solidstate, and gas lasers are also frequently customized.

Table 2. Pooled OLS regression of the relationship between the number of submarkets and market pioneering capabilities

	No. of Laser Submarkets
Pioneering Capabilities	0.644***
	[0.0805]
Advertiser	1.749***
	[0.141]
Foreign Firm	-0.0233
	[0.0753]
log(Employees)	0.179***
	[0.0393]
Incumbent in 1997	0.0626
	[0.0846]
Constant	1.916***

	[0.129]
Log Likelihood	-12147.4
Observations	4993

Standard errors in brackets
* p<0.1, ** p<0.05, ***p<.01

Note: The results suggest that firms with market pioneering capabilities are more likely to be in more submarkets.

Table 3. Market Pioneering Capabilities and Firm Survival, Complementary log-log model of firm survival

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	Survival	Survival	Survival	Survival	Survival	Survival
No. of Laser Submarkets	0.0377***	0.00779	-0.00212	-0.0180	0.000657	0.00305
	[0.00957]	[0.0126]	[0.0140]	[0.0146]	[0.0154]	[0.0156]
No. of Laser Submarkets with Pioneering Capabilities		0.0324**	0.0355**	0.0416**	-0.0112	-0.0136
		[0.0165]	[0.0157]	[0.0167]	[0.0256]	[0.0256]
No. of Submarkets as Distributor		0.0400**		0.0322*	0.0250	0.0200
		[0.0174]		[0.0179]	[0.0179]	[0.0181]
Foreign Firm		0.0433		0.0290	0.0539	0.0396
		[0.0510]		[0.0514]	[0.0518]	[0.0522]
Advertiser		0.271***		0.272***	0.295***	0.292***
		[0.0658]		[0.0660]	[0.0667]	[0.0693]
Incumbent in 1997		-0.0200		-0.0154	0.0465	0.0322
		[0.0584]		[0.0599]	[0.0615]	[0.0619]
Gas Laser Firm			0.152**	0.145**	0.109	0.0635
			[0.0618]	[0.0638]	[0.0703]	[0.0721]
Dye Laser Firm			0.0504	0.0326	-0.0272	-0.0338
			[0.0810]	[0.0822]	[0.0963]	[0.0968]
Diode Laser Firm			0.230***	0.212***	0.188***	0.202***
			[0.0643]	[0.0643]	[0.0699]	[0.0714]
Solidstate Laser Firm			0.200***	0.188***	0.135**	0.128*
			[0.0625]	[0.0630]	[0.0689]	[0.0693]
log(Employees)					-0.0604***	-0.0587***
					[0.0156]	[0.0160]
Pioneering Capabilities in Solidstate					0.206**	0.210**
					[0.0896]	[0.0900]
Pioneering Capabilities in Diode					0.120	0.122
					[0.0916]	[0.0916]

Pioneering Capabilities in Gas					0.185*	0.209**
					[0.104]	[0.104]
Pioneering Capabilities in Dye					0.197	0.189
					[0.165]	[0.165]
Integrated with Detectors						-0.0183
						[0.0753]
Integrated with Electronics						-0.0254
						[0.0601]
Integrated with Fabrication						-0.0593
						[0.0871]
Integrated with Fiber						-0.0592
						[0.0567]
Integrated with Imaging						0.0727
						[0.0665]
Integrated with Light Source						-0.0316
						[0.0704]
Integrated with Material						-0.0257
						[0.0678]
Integrated with Optical						-0.0546
						[0.0548]
Integrated with Position						0.124*
						[0.0706]
Integrated with Service						0.0595
						[0.0574]
Integrated with System						-0.0131
						[0.0520]
Integrated with Testing						0.0918
						[0.0649]
Constant	0.578***	0.556***	0.394***	0.384***	0.478***	0.508***
	[0.0377]	[0.0643]	[0.0626]	[0.0801]	[0.0847]	[0.0928]
lnsig2u						
Constant	-1.544***	-1.558***	-1.540***	-1.571***	-1.605***	-1.649***
	[0.223]	[0.226]	[0.222]	[0.227]	[0.235]	[0.240]
Log Likelihood	-1826.0	-1812.4	-1816.7	-1805.3	-1793.2	-1788.3
Chi-Squared	15.48	39.18	33.04	51.49	70.66	78.88
Observations	4998	4993	4998	4993	4993	4993

Standard errors in brackets
* p<0.1, ** p<0.05, *** p<0.01

Table 4. Market Pioneering Capabilities *at Entry* and Firm Survival, Complementary log-log model of firm survival

	(1)	*(2)*
	Survival	Survival
Survival		
No. of Laser Submarkets	-0.00559	-0.00388
	[0.0148]	[0.0150]
No. of Laser Submarkets with Pioneering Capabilities	0.00973	0.00852
	[0.0206]	[0.0205]
No. of Submarkets as Distributor	0.0216	0.0167
	[0.0180]	[0.0182]
Foreign Firm	0.0563	0.0422
	[0.0520]	[0.0524]
Advertiser	0.304***	0.300***
	[0.0667]	[0.0693]
Incumbent in 1997	0.0574	0.0428
	[0.0617]	[0.0621]
Gas Laser Firm	0.160**	0.118*
	[0.0698]	[0.0715]
Dye Laser Firm	-0.0195	-0.0296
	[0.0918]	[0.0924]
Diode Laser Firm	0.182***	0.195***
	[0.0683]	[0.0697]
Solidstate Laser Firm	0.158**	0.154**
	[0.0678]	[0.0682]
log(Employees)	-0.0611***	-0.0594***
	[0.0157]	[0.0160]
Pioneering Capabilities in Solidstate at Entry	0.160*	0.156*
	[0.0833]	[0.0837]
Pioneering Capabilities in Diode at Entry	0.165*	0.168*
	[0.0867]	[0.0865]
Pioneering Capabilities in Gas at Entry	0.0396	0.0579
	[0.105]	[0.105]
Pioneering Capabilities in Dye at Entry	0.209	0.212
	[0.154]	[0.154]
Integration Variables		YES
Constant	0.458***	0.489***
	[0.0855]	[0.0938]
lnsig2u		
Constant	-1.594***	-1.635***
	[0.233]	[0.238]

Log Likelihood	-1792.9	-1788.3
Chi-Squared	70.80	78.46
Observations	4993	4993

Standard errors are in brackets
* p<0.1, ** p<0.05, *** p<0.01

Table 5. Cox proportional hazards model and Exponential hazard model of firm exit rate

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	Exit	Exit	Exit	Exit	Exit	Exit
Model Description	*Cox*	*Exp*	*Exp + Gamma*	*Exp + Inv Gaussian*	*(3)+Shared Frailty*	*(4) + Shared Frailty*
No. of Laser Submarkets	-0.0164	-0.0280	-0.0258	-0.0263	-0.0265	-0.0268
	[0.0287]	[0.0301]	[0.0315]	[0.0313]	[0.0297]	[0.0295]
No. of Laser Submarkets with Pioneering Capabilities	0.0418	0.0398	0.0404	0.0404	0.0396	0.0397
	[0.0590]	[0.0614]	[0.0625]	[0.0623]	[0.0547]	[0.0545]
No. of Submarkets as Distributor	-0.0637	-0.0690	-0.0727	-0.0720	-0.0707*	-0.0704*
	[0.0462]	[0.0487]	[0.0513]	[0.0509]	[0.0401]	[0.0399]
log(Employees)	0.0914***	0.0933***	0.0969***	0.0963***	0.0940***	0.0939***
	[0.0257]	[0.0281]	[0.0285]	[0.0284]	[0.0273]	[0.0272]
Foreign Firm	-0.0657	-0.0547	-0.0638	-0.0624	-0.0597	-0.0589
	[0.0787]	[0.0859]	[0.0881]	[0.0878]	[0.0891]	[0.0886]
Advertiser	-0.514***	-0.563***	-0.576***	-0.574***	-0.562***	-0.562***
	[0.121]	[0.121]	[0.127]	[0.126]	[0.137]	[0.137]
Incumbent in 1997	-0.0537	-0.134	-0.128	-0.129	-0.125	-0.127
	[0.0974]	[0.103]	[0.105]	[0.105]	[0.108]	[0.107]
Gas Laser Firm	-0.0821	-0.0937	-0.0926	-0.0929	-0.0900	-0.0907
	[0.123]	[0.131]	[0.138]	[0.137]	[0.130]	[0.129]
Dye Laser Firm	0.177	0.211	0.208	0.209	0.203	0.204
	[0.138]	[0.150]	[0.155]	[0.155]	[0.164]	[0.164]
Diode Laser Firm	-0.280**	-0.277**	-0.296**	-0.293**	-0.292**	-0.290**
	[0.123]	[0.130]	[0.136]	[0.135]	[0.131]	[0.130]
Solidstate Laser Firm	-0.133	-0.133	-0.138	-0.137	-0.140	-0.139
	[0.124]	[0.132]	[0.137]	[0.136]	[0.127]	[0.126]
Pioneering Capabilities in Solidstate	-0.393**	-0.371**	-0.398**	-0.394**	-0.381**	-0.380**
	[0.174]	[0.182]	[0.188]	[0.187]	[0.177]	[0.177]
Pioneering Capabilities in Diode	-0.253	-0.275	-0.279	-0.278	-0.273	-0.274
	[0.167]	[0.173]	[0.180]	[0.179]	[0.174]	[0.173]
Pioneering Capabilities in Gas	-0.407**	-0.409**	-0.423**	-0.421**	-0.413**	-0.413**
	[0.184]	[0.197]	[0.205]	[0.203]	[0.190]	[0.189]

Pioneering Capabilities in Dye	-0.435*	-0.477*	-0.485*	-0.484*	-0.474	-0.475
	[0.256]	[0.277]	[0.287]	[0.285]	[0.294]	[0.293]
Vertical Integration Variables	YES	YES	YES	YES	YES	YES
Constant		-1.796***	-1.746***	-1.752***	-1.756***	-1.761***
		[0.162]	[0.167]	[0.166]	[0.173]	[0.172]
ln_the						
Constant			-2.244***	-2.330***	-2.469**	-2.574**
			[0.792]	[0.822]	[1.164]	[1.309]
Log Likelihood	-3881.9	-1264.0	-1263.3	-1263.4	-1263.6	-1263.6
Chi-Squared	81.50	85.41	85.57	86.02	87.75	88.41
Observations	4993	4993	4993	4993	4993	4993

Standard errors in brackets
* p<0.1, ** p<0.05, *** p<0.01

Table 6. Number of premarket approvals for laser-based medical devices as applied by firms with market pioneering capabilities

Company	*Premarket Approvals*
Cynosure	38
Trimedyne	27
Laser Photonics	14
Ion Laser Technology	9
Intralase	8
American Laser Corp	5
Cao Group	3
IRIDEX	3
Light Age	3
Star Medical	3
Union Carbide	2
Schwarz Electro Optics	2
Summit Technology	2
Big Sky Laser Technologies	1
Convergent	1
Cook Corp	1
Equilaser	1

Table 7. Descriptive Statistics

Var No.	*Variable*	*Mean*	*Std. Dev.*	*Min*	*Max*
1	Survival	0.88	0.33	0.00	1.00
2	No. of Laser Submarkets	3.07	2.89	1.00	37.00
3	No. of Laser Submarkets with Pioneering Capabilities	1.02	1.98	0.00	27.00
4	No. of Lasers as Distributor	0.79	1.70	0.00	22.00
5	log(Employees)	2.92	1.61	0.00	10.00
6	Foreign Firm	0.46	0.50	0.00	1.00
7	Advertiser	0.19	0.40	0.00	1.00
8	Incumbent in 1997	0.77	0.42	0.00	1.00
9	Gas Laser Firm	0.37	0.48	0.00	1.00
10	Dye Laser Firm	0.13	0.34	0.00	1.00
11	Diode Laser Firm	0.46	0.50	0.00	1.00
12	Solidstate Laser Firm	0.53	0.50	0.00	1.00
13	Pioneering Capabilities Dymmy	0.40	0.49	0.00	1.00
14	Solidstate Laser Firm * Pioneering Capabilities Dummy	0.21	0.41	0.00	1.00
15	Diode Laser Firm * Pioneering Capabilities Dummy	0.16	0.37	0.00	1.00
16	Gas Laser Firm * Pioneering Capabilities Dummy	0.11	0.31	0.00	1.00
17	Dye Laser Firm * Pioneering Capabilities Dummy	0.04	0.21	0.00	1.00
18	Integrated with Detectors	0.14	0.35	0.00	1.00
19	Integrated with Electronics	0.25	0.43	0.00	1.00
20	Integrated with Fabrication	0.10	0.30	0.00	1.00
21	Integrated with Fiber	0.36	0.48	0.00	1.00
22	Integrated with Imaging	0.22	0.41	0.00	1.00
23	Integrated with Light Source	0.16	0.37	0.00	1.00
24	Integrated with Material	0.19	0.39	0.00	1.00
25	Integrated with Optical	0.43	0.50	0.00	1.00
26	Integrated with Position	0.18	0.38	0.00	1.00
27	Integrated with Service	0.29	0.45	0.00	1.00
28	Integrated with System	0.64	0.48	0.00	1.00
29	Integrated with Testing	0.25	0.43	0.00	1.00

Table 8. Correlation Matrix

No.	*Variable*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
1	Survival	1.00																
2	No. of Laser Submarkets	0.07	1.00															
3	No. of Laser Submarkets with Pioneering Capabilities	0.05	0.56	1.00														
4	No. of Lasers as Distributor	0.05	0.34	-0.02	1.00													
5	log(Employees)	-0.04	0.14	0.11	-0.09	1.00												
6	Foreign Firm	*0.00*	-0.05	-0.09	0.11	0.07	1.00											
7	Advertiser	0.08	0.26	0.20	0.04	0.12	-0.18	1.00										
8	Incumbent in 1997	*0.00*	*0.01*	-0.10	0.06	0.19	-0.08	-0.02	1.00									
9	Gas Laser Firm	*0.02*	0.12	-0.07	0.26	*0.01*	*0.00*	-0.04	0.23	1.00								
10	Dye Laser Firm	*0.01*	0.28	0.14	0.19	*0.02*	-0.13	0.09	0.10	0.12	1.00							
11	Diode Laser Firm	0.04	0.21	0.08	0.06	*0.01*	*0.02*	0.11	-0.12	-0.33	-0.10	1.00						
12	Solidstate Laser Firm	0.04	0.36	0.16	0.20	0.05	0.10	0.06	-0.04	-0.14	*0.01*	-0.20	1.00					
13	Pioneering Capabilities Dymmy	0.05	0.14	0.63	-0.21	0.08	-0.04	0.08	-0.12	-0.11	0.06	*0.00*	0.06	1.00				
14	Solidstate Laser Firm * Pioneering Capabilities Dummy	0.05	0.25	0.57	-0.07	0.07	*0.00*	0.12	-0.11	-0.21	*0.01*	-0.09	0.48	0.62	1.00			
15	Diode Laser Firm * Pioneering Capabilities Dummy	0.04	0.19	0.47	-0.07	*0.02*	-*0.01*	0.11	-0.16	-0.23	-0.06	0.48	-0.09	0.53	0.17	1.00		
16	Gas Laser Firm * Pioneering Capabilities Dummy	0.03	0.07	0.30	-0.09	0.05	-0.08	-*0.01*	0.10	0.45	0.06	-0.20	-0.15	0.43	0.02	-0.03	1.00	
17	Dye Laser Firm * Pioneering Capabilities Dummy	*0.02*	0.16	0.34	-0.03	0.05	-0.09	0.09	0.06	-*0.01*	0.56	-0.07	-0.03	0.26	0.12	0.05	0.14	1.00
18	Intg w Detectors	-*0.01*	0.05	-*0.01*	0.03	0.18	0.02	0.07	*0.02*	-0.09	-0.05	0.22	-0.12	-0.07	-0.08	0.05	-0.09	-*0.01*
19	Intg w Electronics	*0.01*	0.16	0.06	0.06	*0.00*	*0.01*	0.13	0.03	-0.06	0.03	0.22	-0.03	-0.02	0.04	0.06	-0.03	0.02
20	Intg w Fabrication	*0.00*	0.09	*0.02*	-*0.01*	0.16	-0.05	0.14	0.08	0.10	0.05	-0.03	-0.02	*0.00*	-*0.01*	-0.05	0.06	0.03
21	Intg w Fiber	-*0.01*	-*0.01*	*0.00*	-0.03	0.09	-0.03	0.16	-0.04	-0.20	-0.12	0.32	-0.11	-0.06	-0.10	0.16	-0.12	-0.03

22	Intg w Imaging	*0.02*	0.05	-0.04	0.12	0.17	0.04	0.07	0.11	0.06	*0.01*	0.08	*0.02*	-0.08	-0.04	-*0.01*	-0.06	*0.00*
23	Intg w Light Source	*0.01*	0.05	*0.00*	0.05	0.02	-*0.01*	0.14	*0.01*	-0.03	*0.02*	0.12	-0.07	-0.05	-0.06	0.04	-0.05	*0.01*
24	Intg w Material	*0.01*	0.09	0.08	*0.02*	*0.02*	-0.03	0.16	0.04	*0.01*	0.06	*0.00*	0.05	0.06	0.07	-0.04	0.04	0.13
25	Intg w Optical	*0.00*	-*0.01*	-0.05	0.10	*0.01*	-*0.01*	0.12	0.09	0.04	0.03	*0.02*	-0.09	-0.08	-0.07	-0.06	-*0.01*	*0.02*
26	Intg w Position	0.04	0.08	-0.04	0.16	0.07	0.03	0.11	0.12	0.17	0.08	-0.03	*0.01*	-0.11	-0.07	-0.09	-*0.02*	0.07
27	Intg w Service	*0.02*	0.03	*0.01*	0.08	-0.06	-0.13	0.05	0.08	0.21	0.12	-0.15	-0.03	-0.05	-0.04	-0.10	0.08	0.02
28	Intg w System	*0.01*	0.08	*0.00*	0.04	0.07	-0.03	0.06	0.07	0.13	0.06	-0.07	0.07	-0.03	-*0.01*	-*0.01*	-*0.01*	*0.00*
29	Intg w Testing	0.04	0.04	-0.09	0.16	0.02	0.14	0.12	0.13	0.12	*0.00*	0.07	-0.07	-0.13	-0.12	-0.05	-0.06	*0.00*

Table 7. Correlation Matrix (continued)

No.	*Variable*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*
18	Intg w Detectors	1.00											
19	Intg w Electronics	0.20	1.00										
20	Intg w Fabrication	0.13	0.05	1.00									
21	Intg w Fiber	0.27	0.13	0.07	1.00								
22	Intg w Imaging	0.26	0.08	0.27	0.10	1.00							
23	Intg w Light Source	0.27	0.19	0.10	0.21	0.19	1.00						
24	Intg w Material	0.15	0.16	0.23	0.09	0.11	0.18	1.00					
25	Intg w Optical	0.19	0.17	0.18	0.09	0.24	0.13	0.30	1.00				
26	Intg w Position	0.05	0.05	0.14	0.11	0.11	0.09	0.13	0.22	1.00			
27	Intg w Service	-*0.01*	0.03	0.16	0.02	0.07	*0.02*	0.06	0.15	0.16	1.00		
28	Intg w System	-0.05	*0.01*	0.03	-0.02	0.03	-*0.02*	-0.12	-0.06	0.06	0.16	1.00	
29	Intg w Testing	0.19	0.13	0.18	0.16	0.27	0.21	0.09	0.22	0.23	*0.02*	0.04	1.00