Surviving the Gales of Creative Destruction:
The Determinants of Product Turnover

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25 September 2003

ABSTRACT

Innovative industries are often characterized by rapid product turnover. Product longevity may be driven by both a product's position within a market as well as its position within a firm's larger product portfolio. However, we have little understanding of the relative importance of these factors in determining product turnover and how they interact as an industry evolves. Although researchers have invested substantial effort in analyzing *firm* survival and turnover, there are far fewer studies of the determinants of *product* survival and turnover. We use hazard rate models and count regression models to describe the behavior of firms and their products with a new and detailed database on the laser printer industry. We show, first, that competition and market structure variables have a large impact on both speeding product exit and delaying product entry. Second, there is some evidence that firms that have maintained a high market share for a number of years keep their products on the market longer than those with lower market share. Finally, firms with high innovative capacity tend to enter markets frequently, but withdraw their products at average rates. Firms with strong brands tend enter markets at low rates, and withdraw their products slowly. With these findings, the paper links product entry and exit decisions to the broader literature on firm strategic and product portfolio management.

Keywords: Product Turnover; Innovation; Technology Strategy; Industry Dynamics

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Work reported was supported (in part) by the MIT Center for Innovation in Product Development under NSF Cooperative Agreement Number EEC-9529140. We would like to thank Jack Nickerson for assistance with the data. All errors are the sole responsibility of the authors.

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I. INTRODUCTION

Innovative industries are often characterized by rapid product turnover. Product longevity may be driven by both a product's position within a market (i.e., by forces external to the firm that manufactures it) as well as its position within a firm's larger product portfolio (i.e., by internal strategic investment decisions). However, we have little understanding of the relative importance of these factors in determining product turnover and how they interact as an industry evolves.

Although researchers have invested substantial effort in analyzing *firm* survival and turnover (e.g. Hannan and Carroll 1993; Henderson 1995; Mitchell 1991, 1994; Tripsas 1997; Christensen 1997, 1998; Jovanovic 1982; Tushman and Anderson 1986; Ghemawat and Nalebuff 1985; Schumpeter 1942), there are far fewer studies of the determinants of *product* survival, despite the obvious role of products in firm profitability. Theoretical papers are especially scarce on this topic, and rarely consider both market forces and portfolio decisions simultaneously. Adner and Levinthal (2001) address how heterogeneity in consumer demand may influence the types of innovation firms undertake, and the nature of the products that result. However, their emphasis is on product introductions rather than product exit. Klepper and Thompson (2002) demonstrate that a very simple model in which firms make no strategic product development decisions can also explain many regularities of industry dynamics. Empirical work on product exit includes Sorenson (2000), who explores how the breadth of product portfolios affects firm survival rates in computer workstations, and Greenstein and Wade (1998) and Stavins (1995), who estimate product survival rates for mainframes and personal computers, respectively. Like the last two papers, we explicitly model product exit, but in an industry in which there are multiple performance criteria or dimensions of innovation. In addition, this paper distinguishes between the external industry structure determinants of product survival and the role of portfolio considerations internal to the firm.

In analyzing product entry and exit decisions, this paper contributes to our understanding of how new technologies are adopted in broad product portfolios within firms, and in a competitive environment across firms. We exploit a new database on the laser printer industry, which we examine for a number of reasons. First, the performance of laser printers has consistently improved over time and can be easily observed. Second, we are able to track the entry and exit of nearly every product in the industry since its inception in 1984 through 1996. Third, the competitive environment varies across the product space and over time, providing some identification power. Fourth, there are heterogeneous firms of different sizes and with varied backgrounds. Finally, and perhaps most importantly, the laser printer industry shares many characteristics with other high technology industries, such as personal and mainframe computers, disk drives, mobile phones, retail electronics, and the like. The products are differentiated; there is an innovation frontier; there is an important mass market; and product and firm turnover is prevalent. Like other industries, technical advances frequently give rise to market opportunities. The retirement of products occurs as firms introduce new innovations in their new models. These factors affect firms of all sizes, including both incumbents and entrants. Thus the insights from this study may be applicable to broad sectors of the economy.

We use hazard rate models and count regression models to describe the behavior of firms with respect to their product portfolios. We show, first, that market structure and competition variables have a large impact on both speeding product exit and delaying product entry. The number of products in the same product market niche, and in the market as a whole, significantly shortens the lives of products on the market, and can slow the entry of new products. Second, firms with more innovative capacity (as measured by patents) keep their products on the market just as long as their less innovative counterparts. However, these innovative firms introduce products more frequently.[1] Firms with strong brands, however, tend to introduce fewer products and keep those products on their market longer than their weak-brand counterparts. With this information, we develop a theory of product portfolio management to understand the product entry and exit decisions managers engage in. Finally, this paper also has some initial findings regarding the importance of two innovation frontiers for a product, a top frontier that is the traditional "make it better, faster" product innovation frontier, and a bottom frontier that is the "make it cheaper, accessible" frontier. These kind of dual frontiers probably exist in a number of industries, such as personal computers (with the Celeron), DVD players, automobiles, and digital TVs, to name just a few. Investigating the micro-foundations of survival at the product level we believe, in the longer term, help us to understand the determinants of firm survival.

In the next section we state more concretely the hypotheses of the paper that we derive from the literature. A more formal treatment is provided in the Appendix. In the third section of this paper, we describe the desktop laser printer industry, and explain why it is a good arena in which to compare theories empirically. We describe our data and method in Section IV. In

[1] These results are also interesting in further elucidating the "Sony effect." It is widely believed that innovative firms introduce new products onto the market and pull their older, yet profitable, predecessor products in a fast "churn" rate. This paper finds addresses this phenomenon.

Section V, we offer our empirical results. In Section VI, we provide some extensions, and we conclude in Section VII.

II. THEORY: WHY DO PRODUCTS EXIT MARKETS?

Product entry and exit decisions are governed, broadly speaking, by profit maximization and the strategic architecture necessary to achieve that objective. There are three main determinants of product exit. The first, external competitive pressure, drives uncompetitive products out of markets. The second, lack of internal competitive advantage (capabilities, technology), results in relatively high costs of production or an inability to capture the value created by the firm. Finally, there are product portfolio decisions that managers make endogenously based on the market, the innovative capabilities, and the strategy of the firm. Some managers may choose to pull successful products from markets in order to make way for a new model; other managers may choose to leave the older, successful product on the market and not invest in new product innovation; yet other managers may choose to let the older and new product compete on the market. In this sense, product exit is not “failure,” but part of a carefully honed strategy of the firm. In this section, we integrate a number of literatures to develop a framework for generating hypotheses about product exit, product entry, product portfolio decisions, and firm strategy. In the paper we provide a theoretical framework for understanding product exit decisions. This section is based a more formal, yet simple model we develop in the Appendix to this paper.

We begin by noting that products should exit markets when marginal revenue is less than marginal cost. Because in a setting with differentiated products firms have some, but limited, market power, the prevailing price for a product is determined by two factors. The first is the intensity of competition from the firm's own products (sometimes called cannibalization), which is a function of the focal firm's product breadth, *b*. The second is the intensity of competition from other firms' products, which is a function of how many competing products are on the market, *n*.

We model the marginal cost as a function of the scale, or how many printers of a particular model are shipped, *q*; the scope, or how many different models the firm makes (its product portfolio breadth) *b*; and the firm's innovative capacity, *i*.

The profit a product generates for a firm (π) is equal to the price times the quantity minus the cost times the quantity. In its simplest form, a firm's strategy is to launch a product when it has a new model that results in positive profits ($\pi > 0$); the firm withdraws a product that is already on the market when that product starts generating negative profits ($\pi < 0$).

With this framework, we can now discuss product entry and exit decisions, product portfolio choices, and general strategies firms pursue. We begin by examining the issue of competition, embodied in the *n* variable. We assume that as competition increases, prices fall. Thus, the threshold condition for exit rises and the threshold condition for entry is less likely to be met as competition increases.

Thus, we can formalize this in our first set of hypotheses:

<u>Competition Hypotheses:</u>
H1: Exit is increasing in the amount of competition (*n*).
H2: Entry is decreasing in the amount of competition (*n*).

We also consider how costs are affected by quantity sold. In particular, if we assume there are scale economies in production and marketing which firms can effectively exploit for cost advantages, then as the quantity firms sell increases, the cost per unit decreases. As firms increase production, they may achieve scale advantages (Stigler 1968), and may learn how to make products at lower cost (Teece et al 1997, Jovanovic and Lach 1989, Levinthal 1997, Abernathy and Utterback 1978, Klepper 1997). This suggests that $\partial c / \partial q < 0$. Because economies of scale decrease cost, for a given price a lower-cost product is more likely to survive, so the hazard of exit falls. We codify this in our second set of hypotheses.

<u>Scale Hypothesis</u>
H3: Exit is decreasing in quantity of a product sold (*q*).

We now turn to the role of innovation in product entry and exit. Innovation can take the form of product innovation or process innovation. There are two main effects we study here: the direct effect of innovative products, and the more subtle product portfolio ramifications of innovations. Let us first consider the direct effects of innovation on a single product. If consumers value innovations, we would expect that more innovative products survive longer in the marketplace relative to their less innovative counterparts, *ceteris paribus*. We argue that as the innovativeness of the product increases, consumers are willing to pay more for the product. Product innovations in essence allow a firm to command a higher price for its product. Thus, we note that $\partial p / \partial i > 0$. However, there is also a benefit to firms of process innovation in a single product. Process innovations allow firms to decrease costs of products directly through the production process, $\partial c / \partial i < 0$. Thus, innovation can either raise price or lower costs, *ceteris paribus*. This then means that innovative products have a higher threshold for exit. We codify this below:

Innovation Hypothesis

H4: More innovative products will have lower exit rates.

While these first three sets of hypotheses consider individual products, a more complex relationship exists for the firm within its product portfolio. In particular, in a multi-product firm, managers must struggle with the decision of how many products to offer. There are advantages and disadvantages to maintaining broad product lines. First, the broader the product line, the more demand segments and niches a firm can reach with its products in a market with heterogeneous consumers. Thus, the more products a firm maintains, the higher the quantity it is likely to sell, ceteris paribus. That is, $\partial q / \partial b > 0$.

Second, the broader the product line, the more the firm's products will compete with each other. Thus, the firm deals not only with competition from its competitors' products, but also from its own. This is the cannibalization effect (see Schmalensee (1978) for a theoretical model and Greenstein and Wade (1998) for an empirical study of cannibalization). That is, $\partial p / \partial b < 0$.

Third, there may be higher or lower additional costs per unit to maintaining a broad product line. That is, there may be either economies or diseconomies of scope. Having multiple products may allow firms to spread the costs out over a fixed infrastructure. Alternatively, having multiple products may result in more complexity in management and production, and actually raise per-unit costs. This effect, $\partial c / \partial b$, may increase or decrease profits.

With this background, we attempt to identify how a change in product portfolio and product breadth affects the overall profitability of the firm. What becomes evident from this analysis is that there is no easy solution as to whether a large product portfolio will enhance the profitability of a firm or cause it to be unprofitable.

What we can analyze, however, what is likely to drive a firm to higher profits. A more formal statement of this is provided in the Appendix. We find that if two conditions hold, then we may be able to identify the effect of product breadth on profits. If the impact of a firm's product breadth on the product price ($\partial p / \partial b$) is small, and the firm is able to achieve large economies of scope, then profits can increase in product breadth. Thus, we want to know which firms are least likely to lower prices in the face of cannibalizing products, and which firms are most likely to achieve economies of scope.

We argue this is most likely to occur for firms with strong product brands. These firms have created perceived differentiation from their competitors, and customers are willing to pay a price premium for their products. Moreover, because the firm can spread the costs of many products across a single brand, they are likely to achieve economies of scope downstream. Thus, the economies of scope advantage is likely to accrue to firms with strong brands.

We now discuss firm strategies. Firms can pursue either a proliferation (high *b*) strategy, or a focused (low *b*) strategy. Figure 1 summarizes the predictions for product entry and exit resulting from these two strategies. We consider a firm that makes two decisions as part of its strategy: it may or may not launch a new product, and it may or may not withdraw an incumbent product. This results in four cases: (a) no enter, exit; (b) enter, exit; (c) no enter, no exit; and (d) enter, no exit. It is important to note from the outset, that in this product portfolio sense, a decision to exit does not necessarily mean that a product has "failed." It merely means that a profit-maximizing manager has determined that the current product portfolio is not the profit-maximizing one, and that alterations need be made.

In the first case above (no enter, exit), a firm must decide whether to enter a more innovative product. The calculus can be summarizes as follows: the firm examines all of the potential products it can develop, and determines whether any of these options will be profitable. If none of these potential products are profitable, the firm chooses not to develop any of the products and does not launch a new product. Meanwhile, the firm withdraws its current products. This case will arise under two conditions. The firm may be close to leaving the market altogether, so that it introduces no additional products and withdraws its current product offerings. Alternatively, this strategy is consistent with a firm that has attempted product proliferation, and is now contracting to a focused strategy. Although we cannot differentiate between these two strategies from this chart, empirically we do try to control for this by including a variable for firm exit. We call this firm a Focused firm. The second case is one in which the firm withdraws the incumbent product, and replaces it with a more innovative product. This is because the firm believes that the replacement product will be more profitable than the incumbent product individually, or both products together in the market. We call firms that pursue this strategy Innovators, because such firms are cycling through products at a high rate, relying on their innovative capacity to generate new products. The third case is one in which the firm chooses not to introduce a new product because the old product is more profitable than the potential new product and more profitable than having both products in the market together. We call a firm pursuing this strategy Stagnant, because the firm relies on its old products and does not introduce new products into its portfolio. In the final case the firm introduces a new product, but does not withdraw the incumbent product because the profit generated from having both products in the market exceeds that of a single product. We label firms adopting this approach Proliferators. Theories in the literature support each of these different yet mutually exclusive cases (Lee and Tang (1997); Randall, Ulrich and Reibstein (1998); and Kekre and Srinivasan (1990)).

Now that we have these four potential product portfolio cases, we can consider how to link the earlier discussion on product portfolios with these four firm strategies. We ask what firm characteristics are likely to fit into each strategy. We note that Product Proliferators and Innovators are those with high innovative capacity to support their entry strategy. These fast innovators are likely to have high entry patterns, all else equal. Stagnant Firms and Product Proliferators must have the ability to support multiple products on the market and have small price declines due to cannibalization. In essence, other things equal, the Stagnant Firms and Proliferators should be able to exploit economies of scope on the cost side, without suffering price cannibalization. Companies with broad portfolios are likely to have strong brands and distribution channels, so that they can spread the costs of multiple products across their infrastructure and marketing.

In Figure 1, we more clearly highlight these differences. We note that innovation should drive entry patterns, and that brands should drive exit patterns. Firms that are not innovators are less likely to enter than their more innovative counterparts; firms that have weak brands are unlikely to benefit from scope economies, and therefore are likely to exit their products sooner than their strong brand counterparts. We codify these two notions in the next hypotheses:

<u>Product Portfolio Hypothesis</u>
H5: Firms with high innovative capacity should be more likely to launch new products than firms with lower innovative capacity.
H6: Firms with strong brands should be less likely to withdraw their products than weaker brand firms.

III. THE LASER PRINTER INDUSTRY

As the personal computer market expanded in 1980s, so too did the market for desktop printers. Hewlett-Packard introduced the first desktop laser printer for the retail market in 1984.

By the end of 1985, 17 firms had introduced 23 models of printers. Figure 2 illustrates the number of firms and models in the industry from the beginning of the industry in 1984 to 1996.[2] At its peak in 1990, the industry had 100 firms. Since that time, the number of firms has fallen off to 87.

Three types of firms populate the industry. Ricoh, IBM, Hewlett Packard, Canon, and Xerox are examples of large, diversified firms with a strong presence. A number of medium-sized firms specialize in multiple printer technologies, such as Lexmark, Kyocera, Genicom, and Kentek. Finally, there are over 100 very small "fringe" firms, which each produce few printer models, ship very few units, and tend to appear in the industry only briefly. Hewlett Packard is the dominant firm in the industry, and has maintained between 45% and 65% market share for most of the industry's history. Table 1 documents the concentration ratios of the top 1, 5, and 10 firms in the industry (noted as the C1, C5, and C10 ratios, respectively).[3] Defining a dominant firm as one that has ever been among the top 10 in market share, we find that dominant firms account for between 87% and 100% (in early years) of the market share in a given year, but they account for only 30-45% of the product models introduced.

We treat each printer with a unique model number as a distinct product whose features do not change after introduction.[4] The number of products on the market has generally been increasing over time, as seen in Figure 2, with a peak at 633 product models in 1996. Figure 3 shows product entry and exit by year. The rate of entry peaked in 1990.[5] Figures 2 and 3 together suggest that a smaller number of firms are offering more diversified product portfolios.

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[2] In 1996, multifunction printers entered the market. This could be considered a radical or "converging" innovation. To avoid mixing incremental innovations with radical ones, we consider only the period through 1996.

[3] The quantity data we possess seem to be sufficiently good to make determinations about the largest firms in the industry. Unfortunately, the coverage of fringe firms and individual models is poor.

[4] Unlike some product markets, firms in this industry do not change printer attributes once the product has been introduced. Rather, they introduce new products.

The average number of products per firm was 8.8 in 1996, up from 1.8 in 1988.[6] We explore this result further in the econometric analyses.

IV. DATA AND METHOD

A. SOURCE OF THE DATA

The information on laser printer characteristics, entry, and exit come from a variety of sources. The primary source is Dataquest's SpecCheck analysis of page printers. Dataquest follows each manufacturer's products and records a variety of product characteristics, including ship date, speed, resolution, and other features. The data were incomplete for many models, so we supplemented this data with information from trade journals, private analysts' reports, and general industry data provided to us by a private consulting firm. We believe the dataset, which covers the industry from its inception in 1984 to 1996, is the most comprehensive available. Over this 13-year period, we are able to record 2,835 printer-year observations. We restrict the analysis to data from 1986-1996, because too few models were introduced in the early years of the industry to permit identification of the econometric models. Though we have attempted to be as thorough as possible, there remain some printers for which we cannot identify all of the independent variables. These have been dropped from the analysis. To identify patterns of innovation we rely on the MicroPatent database, which provided application dates for patents granted in the industry. We limit our analysis to the most relevant patents for the industry come

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[5] This is likely because it was about this time that the home office laser printer market was being developed, and new innovations were coming about to address this fast growing market niche.

[6] In defining the industry, we appealed to the data and to industry experts and trade journals. These sources consistently define the desktop laser printer industry as laser printers that print 0-12 PPM, can be attached to a personal computer, and are small enough to fit on a desk. This industry definition has remained constant over the time period. Our statistical analyses are robust to small definitional changes.

from four patent classes: 271 (sheet feeding and delivering), 355 (photocopying), 359 (optics), and 399 (electrophotography).[7]

B. PATTERNS IN THE DATA

We begin by examining patterns in the data to describe the industry. Although printers can be characterized on a number of dimensions, the two most common measures of printer performance are speed, measured by pages per minute (PPM), and resolution, measured by dots per inch (DPI). Printers are bunched tightly in groups in the performance space. Figure 4 shows the distribution of printer models across the 20 discrete product classes (or niches) in terms of these two characteristics that we defined based on the clear groupings of printers.

Figures 5 and 6 are scatterplots of the distribution of resolution and speed over time, where each circle is a printer model. During the entire time period, firms improved upon printer resolution, while continuing to develop and introduce printers far behind the DPI frontier. In PPM space, however, a slightly different pattern holds. From 1986 to the early 1990s, firms were introducing printers that were faster as well as printers that were slower than existing products, creating a dual frontier. The cost of producing slower printers may have dropped faster than that of higher speed models, enabling easier entry into low-PPM classes. Alternatively, offering a range of speeds may enable firms to meet more consumers' heterogeneous preferences. This dual-frontier of innovation is a departure from most previous academic work,

[7] Given the size of some of the firms (such as IBM), it is also likely that some firms might have patents that cover products other than laser printers. To the extent this is true, it would create noise in the measure, and thus probably bias the coefficient to zero. Nevertheless, it would likely still be a good measure of innovativeness in imaging technology, which would be a good measure of the capability in this domain.

in which improvement along a single dimension is examined (Christensen 1997, Henderson 1995, Greenstein and Wade 1998).[8]

C. VARIABLE DEFINITIONS

We define a product exit as the first year that the product drops out of the dataset. This means that none of the sources reports the printer is being shipped to retailers from the manufacturers, although it may still be available in some retail outlets from inventory. If any one of the sources reports the printer is still being shipped, we record it as still on the market.

One alternative definition of product exit would be when sales reach zero. Unfortunately, the best data available from a private company on the quantity of models shipped by manufacturers have poor coverage or do not record units sold for low volume models or for models of smaller vendors.[9] These data do seem to be realistic at the aggregate sales level for individual product niches and for large firms, but the precision may still be suspect. As extensions to the main regressions, we re-estimate our models using the quantity data in Section VI.

The independent variables are grouped into four categories and defined in Table 2. Product characteristic variables include MODEL AGE, DPI, PPM. POSTSCIPT, HPPCL, MODEL AWARD, and PRICE. Firm characteristics are captured by DOMINANT FIRM, OWN ALL MODELS, OWN NICHE MODELS, and PATENTS. We also include fixed effects for specific firms as noted later in the paper. TOTAL MODELS, SAME NICHE, and SAME DPI/PPM are measures of market structure. PC SALES and INK JET PRICE proxy for the

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[8] This pattern, however, is consistent with Porter (1985). The lower frontier firms are pursuing a "low cost" strategy while the upper frontier firms are pursuing a "differentiation" strategy.

[9] Greenstein and Wade find similar problems with the IDC data in mainframe computing (1998: p. 779, ftn 13-15).

impact of complements and substitutes. In the entry regressions, we include a measure of product development cost, the average wage of a Level 4 engineer as defined by the Bureau of Labor Statistics (WAGE). Finally, LAG OF ENTRY is the lag of the count of products of a firm's entry in the niche.

The descriptive statistics are found in Table 3. The average product stays on the market for three years, and costs almost $2,200. The most prevalent standard is HP-PCL, in 82% of printers, followed by Postscript (a proprietary Adobe standard) in 46% of printers. Although the average printer has increased its resolution, the average speed of the printers has remained constant from the beginning of the industry, consistent with our earlier discussion on the two-edged frontier of innovation. The average number of products per niche is 19.

D. METHOD

We use an exponential hazard rate specification to examine the determinants of product exit over the product life cycle. The flexibility of this method in accounting for censoring, as well as time variant and time invariant independent variables, makes it attractive to study product failure.

In this specification, the individual model is the unit of analysis. The likelihood function for any given observation, i, can be written as:

$$L_i = G_i(t_i)[\mu_i(t)]^{\phi}$$

where $G_i(t)$ is the survivor function, $\mu_i(t)$ is the hazard rate, ϕ is a variable that is one for uncensored cases and zero otherwise, and t_i is the number of periods that product *i* is in the market (Tuma and Hannan 1984). We assume a constant hazard rate of $\mu(t) = \gamma$ (the exponential distribution). The survivor function is then $G(t) = \exp[-\gamma t]$. The following specification is used:

$$\mu(t) = \exp[X(t)\alpha(t)]$$

where $\mu(t)$ is the instantaneous hazard rate for a system at time t and X(t) is a vector of time-varying independent variables. Each $\exp[X(t)\alpha]$ can be thought of as multipliers of the hazard rate, and α can be estimated using maximum likelihood techniques (Carroll 1983, Tuma and Hannan 1984). Because we have data from the beginning of the industry, left censoring is not a problem. We omit all observations for products that were introduced before 1986 (the first year of the econometrics). The estimation procedure accounts for right censoring.

To examine entry, we consider a count model. In this analysis, each observation is a firm-niche-year observation , and the dependent variable is the count of products introduced by the firm in a given niche-year. Once a firm has entered the market, a firm becomes at risk for entry into any niche, and it remains at risk for all time periods that it still has a printer on the market.[10]

To estimate these equations, we begin with the assumption that the count variables are Poisson distributed. Unfortunately, specification tests (Cameron and Trivedi 1986) indicate

[10] We have coded the data in this way because we believe that the decision to enter the market at all is fundamentally different than a decision to continue in the marketplace.

there is overdispersion in the data. Overdispersion occurs when the Poisson model assumption that the conditional mean of the event counts equals the variance is violated. We therefore estimate the model negative binomial regressions, which allows for overdispersion. It sets the condition mean at $E(y_i \mid x_i) = u_i = \exp[x_i \beta]$, but allows the variance to take the form $V(y_i \mid x_i) = (1+\alpha)u_i$. Each of the parameters of $(\exp[x_i \beta])$ can be thought of as multipliers of the rate of product introduction.

E. IMPLEMENTING THE HYPOTHESES

Table 4 lists the hypotheses described in Section III and the expected sign of the coefficients of variables that relate to them. The first and second hypotheses predict that intense competition results in higher product exit rates, so we expect increases in TOTAL MODELS and SAME NICHE to increase the exit rates of products, and TOTAL MODELS and SAME NICHE to deter potential entrants. This would suggest that that in the exit regressions, we should see higher hazard rates attributable to increases in TOTAL MODELS and SAME NICHE, while in the entry analysis, we should see lower entry rates attributable to these variables.[13]

The third hypothesis predicts that the products of firms with a lower cost position will have a lower probability of product exit. While we do not possess precise data on the number of units sold by product model, we do have reasonable data on the market share of the firm. DOMINANT IN YEAR status should lower the hazard rate if economies of scale are being exploited. However, because market share position could be an indication of either lower cost

[13] If there is competition from neighboring niches, we would expect increases in SAME PPM and SAME DPI to increase the hazard rate as well.

position or market power, our test will only allow us to reject the cost hypothesis, not to differentiate between cost and market power explanations.

The fourth hypothesis predicts managers will withdraw less innovative products off the market before they withdraw more innovative products. This would suggest negative coefficients on PPM and DPI. However, as noted earlier, innovative products will be on both frontiers in the PPM space. Thus the relationship between survival and PPM in this industry (and industries like it) will be nonlinear and non-monotonic. We expect to see greater survival rates on both frontiers. PPM should increase the hazard rate and PPM-squared should have a negative coefficient if both frontiers have higher survival prospects.

In order to examine the product portfolio hypothesis, we use a number of variables.[14] We begin with the effect of innovation on product entry decisions as outlined in Hypothesis 5. We use PATENTS to measure the innovative activity of the firm. Hypothesis 5 suggests that firms with more innovative capacity should be more likely to enter. Thus, in the entry regressions, we should see a multiplier of greater than one on the PATENTS variable if this theory holds.[15]

We now turn to Hypothesis 6. This states that firms with strong brands should be less likely to withdraw their products. We include dummy variables for product made by firms with the strongest overall brands: HP, IBM, DEC, XEROX, and CANON. If brands provide products

[14] Given Hypotheses 5 and 6 involve endogenous managerial decision-making—product exit and product entry—one would want a structural model that involves estimating a hazard rate model for product exit and a dichotomous dependent variable model for product entry. This would require that the hazard rate model have an endogenous variable on the right hand side. However, in general, the coefficient estimates from such an estimation procedure are inconsistent (Hausman 2001). There is not a hazard rate model method that has been developed that generates unbiased estimates of such models of which we are aware. Development of these empirical methods is beyond the scope of this paper. Rather than test these hypotheses in a structural way, we will attempt to describe some of the patterns of behavior that occur in this industry that may be consistent or inconsistent with the hypotheses, though this approach does not constitute a "test" of the hypotheses.

[15] We have no strong priors about the way firms behave with respect to product exit. If firms are Innovators, they may choose to exit their products more quickly. However, if more Product Proliferators, they will withdraw their products at the same rate as their less-innovative counterparts. The expectation is that the coefficient on PATENTS in hazard rate models should not be negative. However, both a statistically significant positive coefficient and a statistically insignificant coefficient are consistent with the theory.

"staying power" on the market, then the multiplier on these variables should be less than one and statistically significant in the hazard rate models, consistent with Hypothesis 6. Table 4 summarizes the predictions and tests of the hypotheses.

We also include a number of additional variables to control for different organizational structures, unobserved demand, and unobserved product quality. REBRAND is a dummy variable equal to one if the product is made by an original equipment manufacturer and then rebranded. ENGINE MANUFACTURER is a dummy variable equal to one if the firm also makes laser engines.[16] OWN ALL MODELS controls for the number of models the firm has on the market at the same time as the focal model. PC SALES and INK JET PRICE proxy for demand for complements and substitutes, respectively. MODEL AWARD is a dummy variable equal to one if the printer received an editor's choice award from PC Magazine; FIRM AWARD is equal to one if any of a firm's products received such an award. Finally, HEDONIC RESIDUAL is difference between a product's actual suggested retail price and that predicted by a hedonic price equation.[17]

V. RESULTS

A. EXIT

We present five models in Table 5. The first number next to each variable name is the hazard ratio (or multiplier of the hazard rate). A value of less than one indicates that an increase

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[16] Some manufacturers of laser printers are backward integrated into laser engine manufacturing, which may affect their behavior in the downstream printer market (de Figueiredo and Teece 1996). In particular, they may be less likely to have product turnover because they are tied to their own laser engines. We include a dummy variable, ENGINE MANUFACTURER, to control for such firms.

[17] HEDONIC RESIDUAL is the residual from a hedonic price equation[17], and is the difference between the product's predicted and actual prices. A high price, for example, could indicate a high cost structure, or unobserved quality that merits a price premium (Stavins 1995). Results of this econometric analysis are available from the authors.

in the variable lowers the hazard rate (and would be equivalent to a negative coefficient); a value of more than one indicates that an increase in the variable raises the hazard rate (and would be equivalent to a positive coefficient). The robust standard errors are presented in parentheses below the hazard ratios. The significance is shown for two-tailed t-tests at the 99%, 95% and 90% significance levels.

Model 1 presents results from a specification that includes variables related to age (MODEL AGE, TIME TREND), product characteristics (POSTSCRIPT, HP-PCL, MODEL AWARD, DPI, PPM, PPM-squared, PRICE), and firm characteristics (FIRM AWARD, OWN ALL MODELS, OWN NICHE MODELS). Model 2 adds the market structure variables. In Model 3, we include the additional innovation variables. Model 4 adds REPLACEMENT, a variable equal to 1 if the firm introduced a product into the same product niche at the same time it withdrew a product and 0 otherwise. Given that the entry decision is endogenous to the exit decision (as noted in the previous section), we include this specification cautiously, mainly as a discussion point, rather than to provide any structural interpretation of the relationship between entry and exit.

Across the four models, most coefficient estimates are remarkably stable in both their magnitude and statistical significance. A likelihood ratio test indicates Models 2 through 4 have equivalent explanatory power at the 95% level as Model 2. Model 2 outperforms Model 1. Hence, we continue our discussion of the results with reference to Models 2-4.

We now turn to our four hypotheses that relate to exit: H1, H3, H4, and H6. The first hypothesis predicts that competition increases a product's hazard rate. We do find very strong evidence for this hypothesis. The multipliers on both TOTAL MODELS and SAME NICHE are greater than one and statistically significant. In addition, the multiplier on SAME NICHE^2 is less than one and also statistically significant, providing evidence that the effect of SAME NICHE on product exit is nonlinear and concave. The magnitude of the estimated coefficients implies that an additional product in a niche increases the probability of exit by about 10%. Competition in neighboring product niches (SAME PPM, SAME DPI) actually decreases the probability of product exit in the focal class by 0.6% to 1.0%. This interesting result might be because neighboring niches don't compete with focal niches, but advertising externalities may accrue to products in the same speed and resolution niches. It may also be evidence that firms successfully use product differentiation to soften competition. Alternatively, the effect of neighboring competition may not be separately identified from total and same niche measures.

The third hypothesis examines the effect of scale on product survival. We test this using a measure of firm market share, DOMINANT IN YEAR.[20] The coefficient on this variable is statistically significant at the 90% level of confidence. A firm that is in the top 10 in market share in a given year decreases the probability of exit of its product by about 27%. Thus, there is some evidence to suggest that scale economies increase product survival, but these results cannot be differentiated from market power explanations. Thus, as noted earlier, we interpret this result as meaning we cannot reject H3.

Hypothesis 4 addresses whether more innovative products last on the market longer. Printers on the frontier of resolution, or DPI, survive longer on the market than less advanced products. The effect of printer speed is less straightforward. While the magnitudes of the multipliers of PPM and PPM^2 are consistent with our hypothesis that proximity to either the

[20] We recognize that this could be measuring market power or lower cost position, and proceed with our interpretation of the results with this in mind.

high-end or low-end frontier slows exit, neither coefficient is statistically significant. These results suggest together that in the unidimensional frontier space of DPI, leading edge products have higher survival rates, but in the bidimensional frontier space of PPM, this effect, while present, is not statistically significant.

Hypothesis 6 states that firms with strong brands are less likely to withdraw their products. To test this, we created dummy variables for the five companies with strong technological and consumer brands in the United States: HP, IBM, DEC, Xerox, and Canon. The multiplier on each of these dummy variables is less than one, as expected. Two have statistically significant coefficients, and the five coefficients are jointly statistically different from zero at the 90% level of confidence (by a Wald test). Together, these results suggest that firms with strong brands are less likely to withdraw their products from markets than are firms without strong brands.

In Model 4, we examine REPLACEMENT, subject to earlier caveats. We would like to know if a company withdraws a product at the same time it introduces a new one. The coefficient on REPLACEMENT is less than one, but not statistically significant, suggesting exit is not more likely when a firm introduces an additional product into the same niche. However, this result, because of the potential endogeneity of the variable, must be viewed cautiously. We discuss this further in the next section.

Finally, we turn to the control variables. Older products are more likely to be withdrawn relative to newer products. Each passing year increases the probability of withdrawing a product from the market by 22%. PC sales decrease the hazard rates for printers. This suggests that sales of complementary products have a large impact on the product withdrawal patterns of desktop laser printers. The hazard ratio of OWN ALL MODELS is greater than one, implying an increase in the probability that a given product exits by 2.5%, and is statistically significant in every specification. Printers that win awards stay on the market longer. The coefficient on MODEL AWARD means that printers that have won awards in the past have a 23% lower hazard rate than those printers that do not win awards. Finally, the coefficient on the residual from the hedonic pricing equation is much greater than one, and statistically significant, suggesting the unobservable qualities that generate a "high price" are probably due to higher cost, rather than higher quality (in contrast to Stavins 1995).

Overall, we find substantial support (or cannot reject) for H1, H3, and H6. We find that on single-frontier technological trajectory (DPI), there is support for H4, but this does not carry over to dual-frontier technological trajectories (PPM) in a statistically significant way. Competition and market structure have large effects in shortening the longevity of products on the market. Firm characteristics, such as market share, seem to play a moderate role in extending the life of products. Indeed, companies with strong brands do have much lower exit rates than those without strong brands. However, a firm's innovative capacity, as reflected in its patent portfolio, has no statistically significant impact on product withdrawal behavior.

B. ENTRY

In this subsection, we analyze the evidence for Hypothesis 2 and Hypothesis 5, which state that competition and innovation affect entry patterns. Table 6 displays the entry regression results. Model 6 presents the entry model without the patent variable, Model 7 includes the patent variable, and Model 8 offers a model with year and class fixed effects. All models cluster standard errors by firm. The incidence ratio or multiplier is presented with its robust standard error beneath in parentheses. If the multiplier is more than one, an increase in the variable by one unit is associated with an increase in the number of product introductions (like a positive coefficient); numbers less than one mean fewer product introductions (like a negative coefficient). All coefficients are marked for statistical significance on two tailed asymptotic t-tests.[22] In all models, a large number of the coefficients are statistically significant and signed as expected. Here we describe some of the more interesting results

Firms that win awards introduce 96% more products that firm that do not. Competition (SAME NICHE) has a multiplier greater than one that is statistically significant and SAME NICHE^2 has a multiplier less than one that is statistically significant. However, the presence of many products in a niche may also reflect high demand in that niche, which we do not directly observe. We therefore include NICHE DEMAND in Model 9 as a variable. The coefficient is greater than one and statistically significant as they predict, and the coefficient on SAME NICHE declines substantially. Though it is still above one and statistically significant, the combined effect of SAME NICHE and its square is negative if the niche has more than 30 products. This suggests that competition deters additional entry in the case of very crowded markets, providing some support for Hypothesis 2.

The innovation variable, PATENTS, which is the focus of Hypothesis 5, has a statistically significant coefficient that is greater than one in all of the models. This suggests that firms with greater innovative capacity have higher entry rates than those without this innovative capacity. Every ten new patents in the key patent classes corresponds to a 0.5% increase in the rate of entry. The product entry rates would be approximately 45% greater for the average

[22] In specifications not reported here, we included variables for substitutes (ink jet prices), but were unable to disentangle these effects from the wage effects.

innovator with 291 patents in the relevant patent classes than a firm with none. This result is consistent with Hypotheses 5.

Finally, we find that companies with strong brands enter with a lower incidence than those with weaker brands. In Model 9, four of the five company dummy variables have statistically significant coefficients that are negative, and the five are jointly significant at the 99% confidence level.[23]

Taken together, the exit analysis and the entry analysis are consistent with the predictions outlined in Figure 1. While not a test of this hypothesis, the results we provide suggest that future research, with more sophisticated methods yet to be developed, might find it useful to explore Hypotheses 5 and 6.

VI. REFINEMENTS AND EXTENSIONS

In this section, we introduce two refinements to the empirical work that explore the importance of innovation, cannibalization, cost, and competition in determining product turnover rates. The first refinement examines demand. It is reasonable to expect that in product niches where there is strong (and perhaps growing) demand, products that have high cost, high price, or poor quality may survive longer than similar products that are in niches with low demand or slowing growth. To examine this possibility, we include in the hazard rate model a variable called NICHE DEMAND, which is the number of units sold in the product niche in that year. Earlier in the paper, we noted the questionable quality of this measure, but we include it in Model 5 of Table 5 in the hope that even a crude indicator might be useful. Model 5 illustrates

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[23] Only HP has a positive coefficient, and this is not statistically significant. A chi-square test finds the coefficients on these variables are jointly significant at the 99% level.

that the coefficient on NICHE DEMAND is less than one, as expected, and statistically significant at the 99% level, so we can conclude that higher demand in a niche increases survival.

Second, a potential complication in interpreting our results is that our analysis does not distinguish between products withdrawn by surviving firms and those that exit the market because the firm has failed. We cannot include a dummy variable for firm exit in the hazard rate regression because firm exit perfectly predicts product exit. The results from hazard model using only observations from surviving firms are quite similar to the results obtained from the full sample, since 1,200 of the observations correspond to surviving firms. Table 7 compares the characteristics of these firms with those that fail. Surviving firms have 5 times more patents in the relevant patent classes, on average, than exiting firms. These “good” firms have won 8 times the number of product awards, have 3 times bigger product lines, and have higher market share. So while there are substantial differences in firm characteristics, the results in Models 1-4 overwhelmingly reflect the portfolio decisions of surviving firms rather the effects of firm failures.

VII. CONCLUSION

This paper empirically examines product exit and entry in the laser printer industry. This is a turbulent market, displaying frequent product turnover in the face of new technical opportunities. In this sense, it looks like a number of other markets that exhibit frequent product introductions and terminations. Like many young industries, it also contains an interesting expansion in the product space over time and expansion in the degree of competition over time. These patterns frame many interesting questions about the rate of product turnover. Moreover, this is largely unexamined by empirical work, and not well understood in any market.

The paper offers evidence that competition and market structure are strong drivers in determining the longevity of products on the market. In particular, we find evidence that competition both slows product entry (in crowded niches) and speeds product exit. This result is consistent with the external competitive pressure explanations of product survival and turnover. In addition, we find that firms with large market shares are less likely to exit their products that are those with small market shares. Third, we find evidence that products on some of the technological frontiers have lower hazard rates than products behind the frontier. In addition, we demonstrate that in this industry (and likely similar industries) there are actually two frontiers of innovation, and little research has been devoted to understanding the competitive dynamics of the lower frontier.

Perhaps the most substantial finding of this paper is with respect to product portfolio strategies. Figure 7 summarizes the findings of this paper. We find that the innovative capability of the firm, as reflected in its stock of knowledge (measured by relevant patents) increases the incidence of entry. However, seem to have no effect on product withdrawals.

Companies with strong brands, on the other hand, have lower incidence of entry, and also have lower hazard rates of product exit than other firms. The relationship between brands and product entry was not anticipated by our theory. What happens when a firm is highly innovative and has a strong brand? These types of firms have lower exit rates for their products. However, the effects of brands and patents on product entry operate in opposite directions. It is an empirical question as to which dominates. We have calculated this effect for a number of firms and we find that innovation effect swamps the brand effect when it comes to entry. That is, firms which are both innovative and have strong brands have high incidence of entry, and low rates of product exit. It is these types of firms that are product proliferators. They enter new products and do not withdraw the older models. This result is also consistent with an extensive literature on product proliferation in differentiated product space to block entry (e.g. Schmalensee 1978, Scherer 1982) and with the marketing literature on brand extension. Note, however, that our work suggests that if academics are to understand this product entry and exit phenomenon, we must examine both horizontal differentiation (brands) and vertical differentiation (innovation) together. As noted in the introduction, other high technology industries, such as personal and mainframe computers, disk drives, fax machines, and retail electronics, where innovation and brands come together in the consumer's purchase decision, are likely to exhibit many of the same effects we see here.

REFERENCES

Abernathy, W. and J. Utterback (1978). "Patterns of Industrial Innovation," Technology Review 80: 40-47.

Adner, Ron and Daniel Levinthal (2001). "Demand Heterogeneity and Technology Evolution: Implications for Product and Process Innovation," Management Science 47(5): 611-628.

Cameron, A, and P. Trivedi (1986). "Econometric Models Based on Count Data: Comparisons and Applications of Some Estimators and Tests," Journal of Applied Econometrics 1: 29-53.

Carroll, Glenn R. (1983). "Dynamic Analysis of Discrete Dependent Variables: A Didactic Essay," Quality and Quantity 17: 425-460.

Carroll, Glenn R. (1985). "Concentration and Specialization: Dynamics of Niche Width in Populations of Organizations," American Journal of Sociology 90(6): 1262-1283.

Christensen, Clayton M. (1997). The Innovator's Dilemma. (Boston: Harvard Business School Press).

Christensen Clayton M., Suarez Fernando F., and Utterback James M. (1998). "Strategies for survival in fast-changing industries," Management Science 44(12): S207-220.

de Figueiredo, John M., and David J. Teece (1996). "Mitigating Procurement Hazards in the Context of Innovation," Industrial and Corporate Change 5(2): 537-559.

Ghemawat, Pankaj, and Nalebuff, Barry (1985). "Exit," Rand Journal of Economics 16(2): 184-94.

Greenstein, Shane M., and James B. Wade (1998). "The Product Life Cycle in the Commercial Mainframe Computer Market, 1968-1982," Rand Journal of Economics 29(4): 772-789.

Hannan, Michael T., and Glenn R. Carroll (1993). Dynamics of Organizational Populations. New York: Oxford University Press.

Hausman, Jerry (2001). "Mismeasured Variables in Econometric Analysis: Problems from the Right and Problems from the Left," Journal of Economic Perspectives 15(3).

Henderson, Rebecca (1995). "Of Life Cycles Real and Imaginary: The Unexpectedly Long Old Age of Optical Lithography," Research Policy 24: 631-643.

Jovanovic, Boyan (1982). "Selection and the Evolution of Industry," Econometrica 50: 649-670.

Jovanovic, Boyan, and Saul Lach (1989). "Entry and Exit with Learning by Doing," American Economic Review 79: 690-699.

Kekre, Sundar and Kannan Srinivasan (1990). “Broader Product Line: A Necessity to Achieve Success?” Management Science 36(1), 1216-1231.

Klepper, Steven (1997). “Entry, Exit, Growth, and Innovation over the Product Life Cycle,” American Economic Review 86: 562-583.

Klepper, Steven and Peter Thompson (2002). “Submarkets and the Evolution of Market Structure,” Carnegie-Mellon University Working Paper.

Lee, Hau and Christopher Lee (1997). “Modelling the Costs and Benefits of Delayed Product Differentiation,” Management Science 43(1), 40-53.

Levinthal, Daniel (1997). “Adaptation on Rugged Landscapes,” Management Science 43(7): 934-950.

Mitchell, Will (1991). “Dual Clocks: Entry Order Influences on Incumbent and Newcomer Market Share and Survival When Specialized Assets Retain their Value,” Strategic Management Journal 12(2): 85-100.

Mitchell, Will (1994). “The Dynamics of Evolving Markets: the Effects of Business Sales and Age on Dissolutions and Divestitures,” Administrative Science Quarterly 39: 575-602.

Randall, Taylor, Karl Ulrich and David Reibstein (1998). “Brand Equity and Vertical Product Line Extent,” Marketing Science 17(4), 356-379.

Scherer, Frederick M. (1982). “The Breakfast Cereal Industry,” in The Structure of American Industry (6th ed.), W. Adams, ed. (New York: Macmillan).

Schmalensee, Richard (1978). “Entry Deterrence in the Ready-to-Eat Breakfast Cereal Industry,” Bell Journal of Economics 9(2): 305-27.

Schumpeter, Joseph (1942). Capitalism, Socialism, and Democracy. (New York: Harper).

Sorenson, Olav (2000). “Letting the Market Work for You: an Evolutionary Perspective on Product Strategy,” Strategic Management Journal 21: 577-592.

Stavins, Joanna (1995). “Model Entry and Exit in a Differentiated-Product Industry: The Personal Computer Market,” Review of Economics and Statistics 74: 571-584.

Stigler, George J. (1968). The Organization of Industry. (Homewood, IL: Richard D. Irwin).

Teece, David, and Gary Pisano (1994). “Dynamic Capabilities of Firms,” Industrial and Corporate Change, 3:537-556.

Trajtenberg, Manuel (1989) “The Welfare Analysis of Product Innovations, with an Application to Computed Tomography Scanners,” Journal of Political Economy 97(2): 444-479.

Tripsas, Mary (1997). “Unraveling the Process of Creative Destruction: Complementary Assets and Incumbent Survival in the Typesetter Industry,” Strategic Management Journal 18: 119-142.

Tushman, M., and P. Anderson (1986). “Technological Discontinuities and Organizational Environments,” Administrative Science Quarterly 31: 439-465.

Tuma, Nancy B. and Michael T. Hannan (1984). Social Dynamics. (Orlando: Academic Press).

APPENDIX
A MORE FORMAL TREATMENT OF THE THEORETICAL SECTION

We assume firms maximize profit. For each product, the profit that is generated is:

$$\pi = p(n,b,i)q(b) - c(q(b),b,i)q(b) \qquad \text{Eq (1)}$$

The profit a product generates for a firm (π) is equal to the price times the quantity minus the cost times the quantity. The first term is the revenue, which is equal to the price *p(n,b,i)* times the quantity *q(b)*. As noted above, the price is affected by the number of competitor products on the market *(n)* and the number of the firm's own products on the market *(b)*. The quantity the firm sells is related to the product breadth (or number of products in its product portfolio). The second term is the cost per unit, *c(q(b), b, i)*, times the quantity, *q(b)*. Again, the cost is dependent upon quantity sold *(q)*, the breadth of the product line *(b)*, and the innovativeness of the firm *(i)*.

We assume that as competition increases, prices fall. In terms of our profit equation, that would be $\partial p / \partial n < 0$. Thus, the threshold condition for exit rises and the threshold condition for entry is less likely to be met as competition increases. This is the basis for H1 and H2.

We assume there are scale economies in production and marketing which firms can effectively exploit for cost advantages, then as the quantity firms sell increases, the cost per unit decreases. From our profit equation, this suggests that $\partial c / \partial q < 0$. Because economies of scale decrease cost, for a given price a lower-cost product is more likely to survive, so the hazard of exit falls. This is the basis for H3.

We now turn to the role of innovation in product entry and exit, manifested in the profit equation with the variable *i*. If innovativeness of the product increases consumers' willingness to pay for a product, product innovations allow a firm to command a higher price for its product. Thus, in the profit equation, we note that $\partial p / \partial i > 0$. However, there is also a benefit to firms of process innovation in a single product. Process innovations allow firms to decrease costs of products directly through the production process, $\partial c / \partial i < 0$. Thus, innovation can either raise price or lower costs, *ceteris paribus*. This then means that innovative products have a higher threshold for exit. This is the basis for H4

There are advantages and disadvantages to maintaining broad product lines. First, the broader the product line, the more demand segments and niches a firm can reach with its products in a market with heterogeneous consumers. Thus, the more products a firm maintains, the higher the quantity it is likely to sell, ceteris paribus. That is, $\partial q / \partial b > 0$.
Second, the broader the product line, the more the firm's products will compete with each other. That is, $\partial p / \partial b < 0$. Third, there may be higher or lower additional costs per unit to maintaining a broad product line. That is, there may be either economies or diseconomies of scope. In our model, we note this effect as $\partial c / \partial b$, but have no theoretical prediction for its sign.

We attempt to identify how a change in product portfolio and product breadth affects the overall profitability of the firm. We take the first derivative of the profit equation to generate a first order condition yielding the following equation:

$$\frac{\partial \pi}{\partial b} = \left[\frac{\partial p}{\partial b} q(b) + p(n,b,i) \frac{\partial q}{\partial b} \right] - \left[\frac{\partial q}{\partial b} \frac{\partial c}{\partial b} q(b) + c(q(b),b,i) \frac{\partial q}{\partial b} \right] \qquad \text{Eq (2)}$$

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[(-) + (+)]- [(?) + (+)]

Although seemingly messy, we have indicated the sign of each term below the equation. What becomes evident from this analysis is that there is no easy solution as to whether a large product portfolio will enhance the profitability of a firm or cause it to be unprofitable. This is because the sign of the first derivative is indeterminate, and depends upon the magnitudes of the partial derivatives.

What we can analyze, however, is what is likely to drive a firm to higher profits. As we can see from Equation 2, if $\partial p / \partial b$ is small, then the first term becomes positive. Also, if a firm is able to achieve sufficiently large economies of scope, then the second term is no longer indeterminate, but is positive ($\partial c / \partial b$ > 0). This is the basis for H5 and H6.

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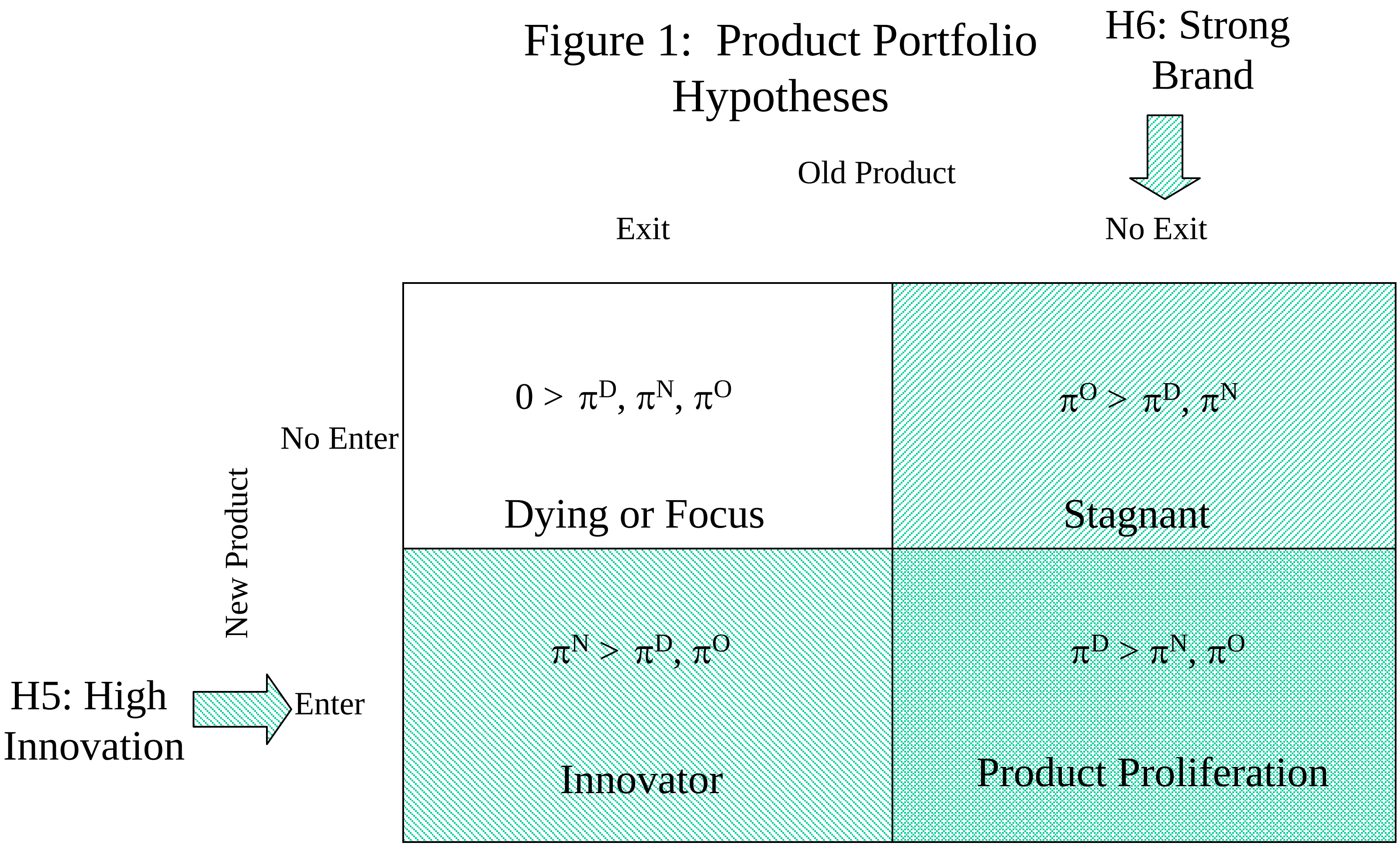
Figure 1: Product Portfolio Hypotheses



π^D = profit of both products in market together
π^N = profit of new product when alone in market
π^O = profit of old product when alone in market

Figure 2: Number of Firms and Products in Marketplace

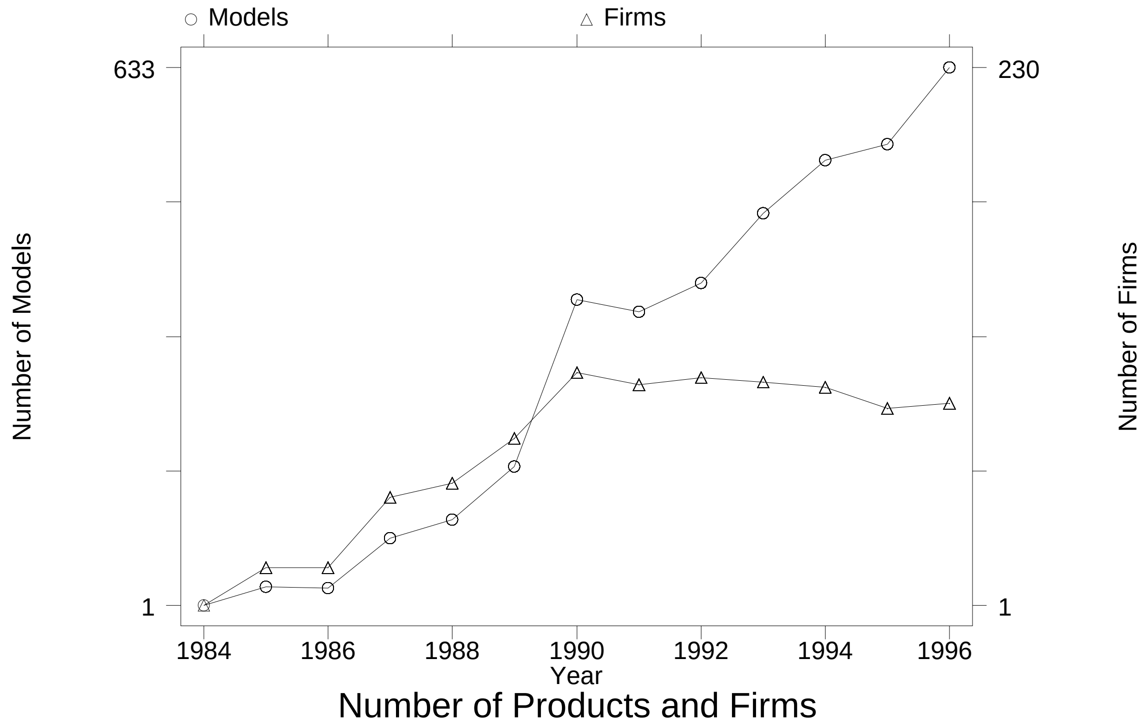


Figure 3: Product Entry and Exit

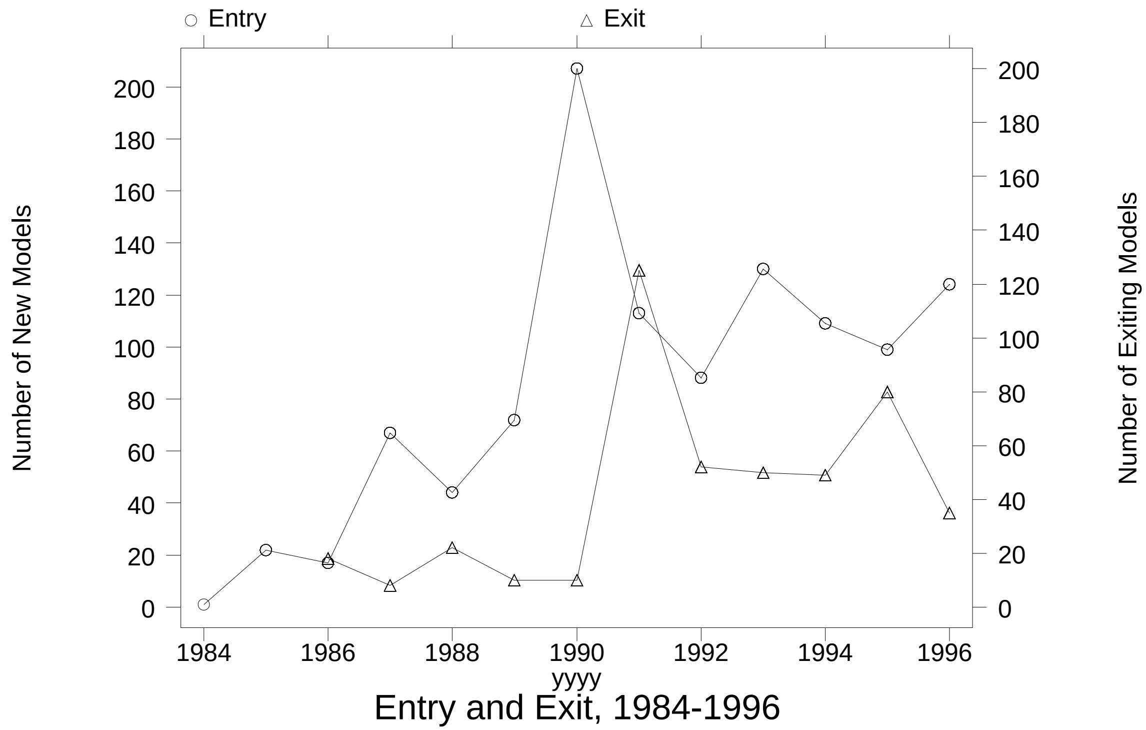
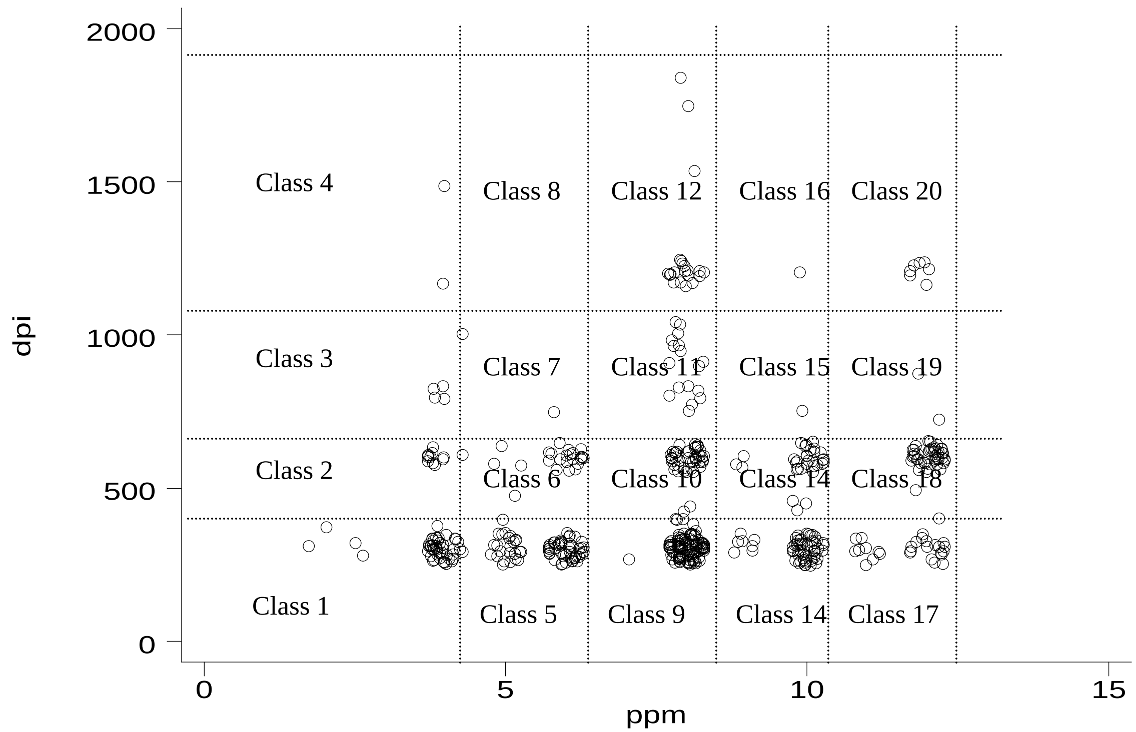


Figure 4: Product Distribution and Classes



Note: Each small circle represents a printer.

Figure 5: DPI by Model

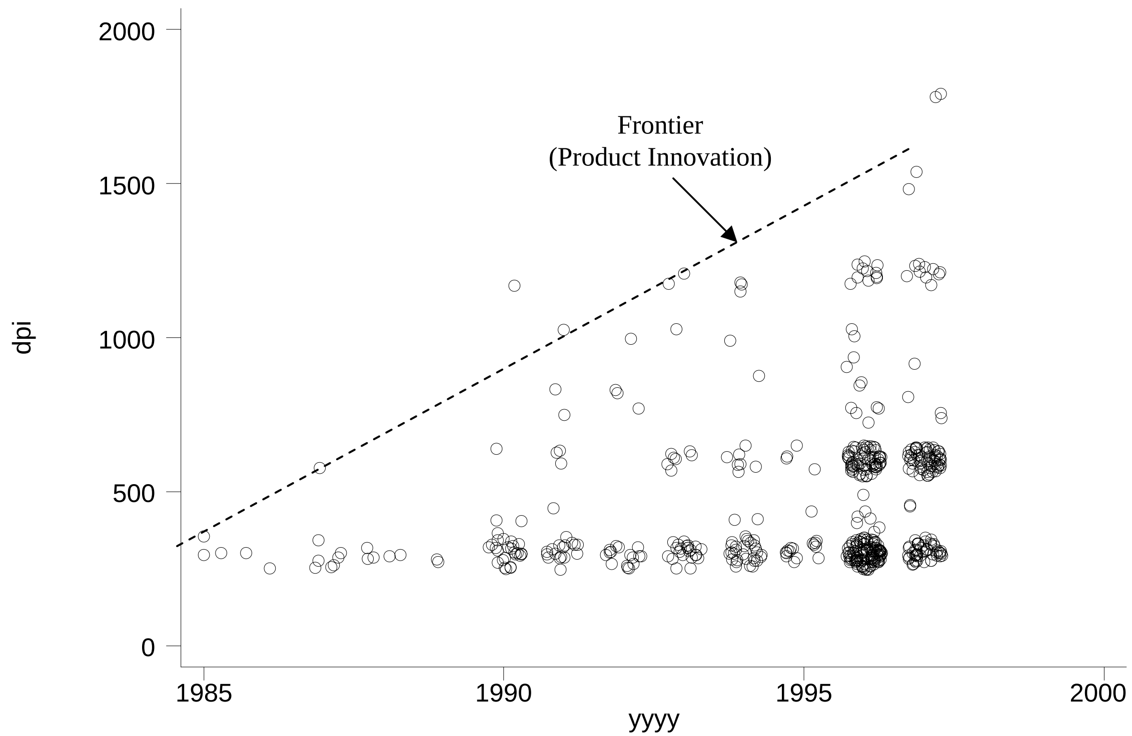


Figure 6: PPM by model

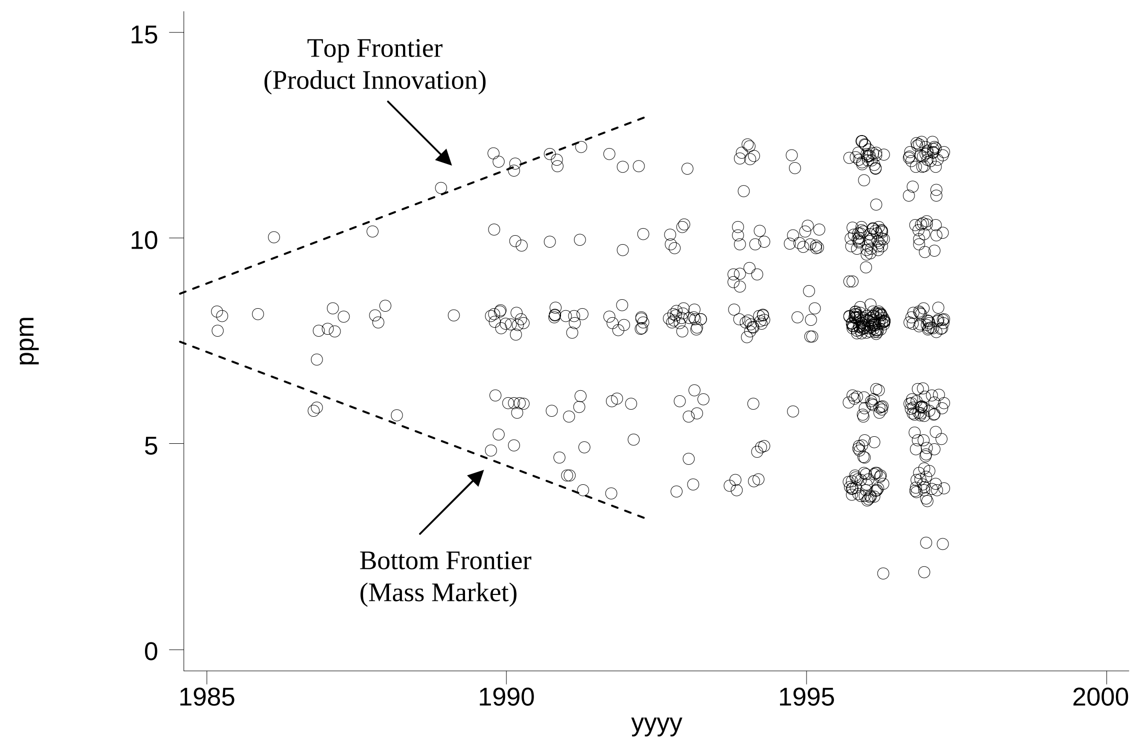


Figure 7: Summary of Product Portfolio Findings

Innovative Firm?	Firm Strong Brand?: No	Firm Strong Brand?: Yes
No	Entry: Average Exit: Average Stagnator	Entry: Low Exit: Slow Marketer
Yes	Entry: High Exit: Average Innovator	Entry: High Exit: Slow Product Proliferator

TABLE 1A: CONCENTRATION RATIOS AND TOTAL SHIPMENTS

Year	Hewlett Packard	C5 Ratio	C10 Ratio	Total Estimated Shipments
1987	58.12%	87.83%	100.00%	411,845
1988	61.66%	87.31%	99.28%	646,097
1989	49.68%	87.48%	98.47%	991,331
1990	54.89%	78.39%	87.44%	1,925,152
1991	48.80%	76.59%	90.13%	2,687,110
1992	50.58%	80.17%	92.89%	2,303,355
1993	57.08%	82.36%	92.92%	2,303,990
1994	55.88%	80.49%	94.42%	2,795,232
1995	60.53%	85.95%	99.62%	2,814,688

TABLE 1B: NUMBER OF YEARS IN TOP TEN IN SHIPMENTS

Firm	Years
HEWLETT-PACKARD_COMPANY	9
IBM/LEXMARK	9
DIGITAL_EQUIPMENT_CORP	8
PANASONIC/MATSUSHITA	8
APPLE_COMPUTER_CO	7
OKIDATA_CORP	7
TEXAS_INSTRUMENTS_INC	7
EPSON_AMERICA_INC	6
NEC_TECHNOLOGIES_INC	6
KYOCERA_UNISON	5
CANON	4
QMS_INC	4
XEROX_CORP	3
BROTHER_INTERNATIONAL_CORP	2
C-TECH_ELECTRONICS_INC	1
FUJITSU_AMERICA_INC	1
GCC_TECHNOLOGIES_INC	1
SUN_MICROSYSTEMS	1
TANDY_CORP	1

TABLE 2: VARIABLE DEFINITIONS

MODEL AGE	The age of the product, measured as the number of years since introduction.
HP-PCL, POSTSCRIPT	Dummy variables for printing standards.
MODEL AWARD and FIRM AWARD	One measure of product quality is to examine whether the printer has won an award for price and performance. Every year, PC Magazine announces 4-10 printer awards for printers that they judge to be particularly good value across the spectrum of printers available, based on features ar predicted reliability. MODEL AWARD equals one if the particular model won an award. FIRM AWARD equals one for all models manufactured by a firm if any of its models won an award in the prior two years.
REBRAND	Dummy variable for whether the product is made by another firm and then just rebranded.
DPI	The log of the printer's resolution, measured in dots per inch.
PPM and PPM-squared	The speed of the printer, measured in pages per minute, and its square.
PRICE	List price of the printer.
HEDONIC RESIDUAL	The value of the residual from the hedonic regression.
DOMINANT FIRM	A dummy variable for whether the vendor was one of the top ten producers in terms of market share for the given year.
UNITS	Number of units shipped in the given year by the firm.
CUMULATIVE UNITS	Total number of units shipped by the firm during the previous and given year.
HP, IBM, DEC, CANON, XEROX	Dummy variable for the individual firms
OWN ALL MODELS	The number of total models the firm currently has in the desktop printer market.
OWN NICHE MODELS	The number of models the firm currently has in the focal class.
ENGINE MANF	Dummy variable for engine manufacturer.
TOTAL MODELS	The number of total models in the desktop laser printer market at the time.
SAME DPI and SAME PPM:	The number of products that are at the same DPI (all classes covering the same DPI), and the number of products that are at the same PPM (all classes covering the same PPM).
SAME NICHE and SAME NICHE^2	The number of products competing in the same local PPM-DPI class as the product under consideration, and its square, respectively.
INK JET PRICE	The average price of ink jet printers in year t.
PC SALES	The number of personal computers sold in the United States in millions in year t.
PATENTS	The number of new patents issued, by application year, in patent classes 271, 355, 359, and 395.
REPLACEMENT	Dummy variable for whether the firm introduced a new printer model in the class in year t.
NICHE DEMAND	Number of units shipped in a given niche in year t.
ENGINEERING WAGE	The average wage of a Level 4 engineer (as defined by the Bureau of Labor Statistics) in year t.
LAG OF ENTRY	The lag of the count of products of a firm’s entry in the class

TABLE 3: DESCRIPTIVE STATISTICS

VARIABLE	MEAN	STD DEV	MIN	MAX
AGE	2.96	1.86	1.00	11.00
POSTSCRIPT	0.46	0.50	0.00	1.00
HP-PCL	0.82	0.38	0.00	1.00
MODEL AWARD	0.11	0.32	0.00	1.00
REBRAND	0.09	0.28	0.00	1.00
LN DPI	5.97	0.41	5.48	7.50
PPM	7.87	2.43	2.00	12.00
PRICE	22.23	18.12	1.40	165.02
HEDONIC RESIDUAL	0.00	0.31	-1.16	1.71
REPLACEMENT	0.42	0.49	0.00	1.00
TOTAL MODELS	402.32	119.58	1.00	500.00
SAME PPM	60.47	29.06	1.00	108.00
SAME DPI	207.02	95.52	1.00	320.00
SAME NICHE	19.38	15.82	1.00	66.00
DOMINANT IN YEAR	0.40	0.49	0.00	1.00
OWN IN NICHE	2.89	2.02	1.00	9.00
OWN MODELS	11.56	10.19	1.00	48.00
FIRM AWARD	0.32	0.47	0.00	1.00
ENGINE MFR	0.20	0.40	0.00	1.00
PATENTS	291.34	1,018.07	0.00	5,602.00
NICHE DEMAND	282,713.40	321,752.20	0.00	1,010,626.00
PC SALES	15.50	4.43	6.80	22.60
INK JET PRICE	3.11	2.09	1.53	12.55
HP	0.04	0.21	0.00	1.00
IBM	0.08	0.28	0.00	1.00
DEC	0.03	0.17	0.00	1.00
XEROX	0.03	0.17	0.00	1.00
CANON	0.03	0.17	0.00	1.00

TABLE 4: OPERATIONALIZATION AND OUTCOMES OF TESTS OF HYPOTHESES

Hypothesis	Variable	Model	Expected Magnitude	Results: Actual Magnitude	Results: Substantive Impact
H1: Competition and Exit	**TOTAL MODELS**	**Hazard Rate**	**> 1**	**> 1**	**Large**
	SAME NICHE	**Hazard Rate**	**> 1**	**> 1**	**Large**
	SAME NICHE^2	**Hazard Rate**	**< 1**	**< 1**	**Moderate**
H2: Competition and Entry	**SAME NICHE**	**Negative Binomial**	**< 1**	**> 1**	**Moderate**
	SAME NICHE^2	**Negative Binomial**	**< 1**	**< 1**	**Moderate**
H3: Economies of Scale	**DOMINANT IN YEAR**	**Hazard Rate**	**<1**	**<1**	**Large**
H4: Innovative Products	**DPI**	**Hazard Rate**	**< 1**	**<1**	**Large**
	PPM	Hazard Rate	> 1	nss	
	PPM-SQUARED	Hazard Rate	< 1	nss	
H5: Product Portfolio: Innovation	**PATENTS**	**Negative Binomial**	**> 1**	**> 1**	**Large**
H6: Product Portfolio: Brands	**HP, IBM, Canon, DEC, Xerox**	**Hazard Rate**	**< 1**	**< 1**	**Large**

Notes: NSS = not statistically significant. > 1 means that the hazard ratio or the incidence ratio is expected to be greater than one; < 1 means that the hazard ratio or incidence ratio is expected to be less than 1. Bolded hypotheses are broadly confirmed by the data, except for parts of Hypothesis 4 and with complexity as described in the paper rega Hypothesis 2. The results do not constitute of a "test" of H5 and 6, but provide descriptive data which is consistent with these hypotheses, as noted above. The magnitude and bolding are based on the magnitude and statistical significance of the coefficients for Models 1-5 (exit) and 6-9 (entry). Substantive impact is subjective, based on magnitude of coefficients.

TABLE 5: HAZARD RATE MODELS FOR PRODUCT EXIT

VARIABLE	MODEL 1 Hazard Ratio (Robust SE)	MODEL 2 Hazard Ratio (Robust SE)	MODEL 3 Hazard Ratio (Robust SE)	MODEL 4 Hazard Ratio (Robust SE)	MODEL 5 Hazard Ratio (Robust SE)
MODEL AGE	1.465*** (0.047)	1.229*** (0.038)	1.230*** (0.038)	1.220*** (0.038)	1.192*** (0.037)
POSTSCRIPT	0.919 (0.131)	0.881 (0.109)	0.877 (0.108)	0.882 (0.108)	0.931 (0.113)
HP-PCL	1.021 (0.238)	0.829 (0.150)	0.831 (0.150)	0.827 (0.144)	0.886 (0.150)
MODEL AWARD	0.671** (0.117)	0.769* (0.112)	0.767* (0.110)	0.764* (0.110)	0.778* (0.106)
REBRAND	1.226 (0.224)	1.036 (0.165)	1.044 (0.167)	1.053 (0.171)	0.955 (0.152)
Ln(DPI)	2.198*** (0.406)	0.384*** (0.117)	0.386*** (0.117)	0.383*** (0.116)	0.485** (0.150)
PPM	0.926 (0.126)	1.197 (0.232)	1.197 (0.231)	1.176 (0.229)	0.914 (0.182)
PPM^2	1.009 (0.009)	0.993 (0.012)	0.993 (0.012)	0.994 (0.013)	1.009 (0.013)
PRICE	0.978*** (0.008)	1.001 (0.006)	1.002 (0.006)	1.002 (0.006)	1.000 (0.006)
HEDONIC RESIDUAL	1.986*** (0.393)	1.460** (0.251)	1.453** (0.250)	1.456** (0.248)	1.423** (0.233)
DOMINANT FIRM	0.727* (0.122)	0.737* (0.124)	0.730* (0.124)	0.729* (0.123)	0.700** (0.118)
HP	0.793 (0.230)	0.667 (0.185)	0.633 (0.183)	0.661 (0.189)	0.587* (0.175)
IBM	0.222*** (0.098)	0.434** (0.166)	0.323** (0.171)	0.340** (0.182)	0.384* (0.189)
DEC	0.563** (0.154)	0.601* (0.175)	0.572* (0.170)	0.579* (0.171)	0.544** (0.160)
XEROX	0.615 (0.334)	0.651 (0.296)	0.485 (0.279)	0.525 (0.309)	0.562 (0.318)
CANON	0.957 (0.296)	0.892 (0.253)	0.582 (0.290)	0.601 (0.299)	0.702 (0.337)
OWN NICHE MODELS	0.973 (0.033)	0.975 (0.029)	0.976 (0.030)	0.984 (0.031)	0.982 (0.031)
OWN ALL MODELS	1.051*** (0.011)	1.025** (0.010)	1.025** (0.010)	1.024** (0.010)	1.022** (0.010)

FIRM AWARD	0.670**	0.920	0.914	0.921	0.986
	(0.126)	(0.157)	(0.154)	(0.157)	(0.170)
ENGINE MANF	1.085	0.950	0.946	0.954	0.899
	(0.199)	(0.141)	(0.140)	(0.136)	(0.126)
PC SALES	0.931***	0.726***	0.726***	0.725***	0.743***
	(0.021)	(0.045)	(0.045)	(0.045)	(0.040)
INK JET PRICE	0.271***	0.637	0.636	0.636	0.617
	(0.055)	(0.299)	(0.299)	(0.297)	(0.270)
TOTAL MODELS		1.024***	1.024***	1.024***	1.020***
		(0.005)	(0.005)	(0.005)	(0.004)
SAME PPM		0.994	0.994	0.994	0.994
		(0.004)	(0.004)	(0.004)	(0.004)
SAME DPI		0.991***	0.991***	0.991***	0.991***
		(0.002)	(0.002)	(0.002)	(0.002)
SAME NICHE		1.088***	1.087***	1.089***	1.119***
		(0.022)	(0.022)	(0.022)	(0.025)
SAME NICHE^2		0.999***	0.999***	0.999***	0.999***
		(0.000)	(0.000)	(0.000)	(0.000)
PATENTS			1.000	1.000	1.000
			(0.000)	(0.000)	(0.000)
REPLACEMENT				0.860	0.945
				(0.139)	(0.152)
NICHE DEMAND					1.000***
					(0.000)
n	1,483	1,483	1,483	1,483	1,483
Log pseudo-likelihood	-209.14	-149.41	-149.31	-149.01	-140.02

Notes: All coefficients are hazard ratios, and reflect a multiplier of the hazard rate. A hazard ratio > 1 is equated to a positive coefficient in the hazard rate model; a hazard ratio of < 1 is equated to a negative coefficient in the hazard rate model. For example, a coefficient of 1.021 means that for every one unit increase in the independent variable, there is a 2.1% increase in the hazard rate. A coefficient of 0.846 means that for every one unit increase in the independent variable, there is a 15.4% decrease in the hazard rate. All t-statistics for the hazard ratios are in parentheses. *** 99% level of significance; ** 95% level of significance; * 90% level of significance.

TABLE 6: NEGATIVE BINOMIAL FOR ENTRY

VARIABLE	MODEL 6 Incidence ratio (SE)	MODEL 7 Incidence ratio (SE)	MODEL 8 Incidence ratio (SE)	MODEL 9 Incidence ratio (SE)
PC SALES	0.891*** (0.017)	0.873*** (0.019)	0.878 (0.131)	0.899 (0.146)
FIRM AWARD	2.250*** (0.607)	1.993*** (0.497)	1.958*** (0.458)	1.926*** (0.434)
ENGINE MANF	1.297 (0.261)	1.245 (0.271)	1.327 (0.292)	1.340 (0.295)
HP	1.848** (0.529)	1.290 (0.374)	1.267 (0.346)	1.330 (0.343)
IBM	2.358*** (0.401)	0.279*** (0.134)	0.286*** (0.128)	0.311*** (0.127)
DEC	1.404*** (0.169)	1.026 (0.152)	0.812 (0.119)	0.793* (0.114)
XEROX	3.043*** (0.541)	0.146** (0.110)	0.167** (0.119)	0.166** (0.116)
CANON	1.355** (0.208)	0.015*** (0.017)	0.013*** (0.014)	0.015*** (0.016)
DOMINANT FIRM	0.979 (0.144)	0.886 (0.128)	0.886 (0.132)	0.901 (0.137)
LAG OF ENTRY	4.024*** (1.047)	3.471*** (1.106)	2.770*** (0.743)	2.702*** (0.739)
ENGINEERING WAGE	1.039*** (0.010)	1.048*** (0.010)	1.052 (0.062)	1.047 (0.068)
SAME NICHE	1.076*** (0.017)	1.072*** (0.017)	1.065*** (0.017)	1.031* (0.020)
SAME NICHE^2	0.999*** (0.000)	0.999*** (0.000)	0.999*** (0.000)	0.999* (0.000)
PATENTS		1.001*** (0.000)	1.001*** (0.000)	1.001*** (0.000)
NICHE DEMAND				1.000*** (0.000)
Year Fixed Effects	no	no	yes	yes
Class Fixed Effects	no	no	yes	yes
alpha	8.835 (1.304)	7.471 (1.271)	6.111 (1.092)	5.872 (1.056)
Obs	9,844	9,844	9,844	9,844
Log pseudo-likelihood	-1538.10	-1497.27	-1452.18	-1444.28

Notes: All coefficients are incidence ratios, and reflect a multiplier of the original coefficients. An incidence ratio > 1 is equated to a positive coefficient in the negative binomial model; an incidence ratio of < 1 is equated to a negative coefficient in the negative binomial model. For example, a coefficient of 1.021 means that for every one unit increase in the independent variable, there is a 2.1% increase in the rate of entry. A coefficient of 0.846 means that for every one unit increase in the independent variable, there is a 15.4% decrease in the rate of entry. All t-statistics for the incidence ratios are in parentheses. *** 99% level of significance; ** 95% lev of significance; * 90% level of significance.

TABLE 7: GOOD VS. EXITING FIRMS

VARIABLE	"GOOD FIRM"		"EXITING FIRM"	
	Mean	Std. Dev	Mean	Std. Dev
AVERAGE MODEL AGE	2.67	1.92	2.06	1.66
POSTSCRIPT	0.49	0.50	0.37	0.49
HPPCL	0.80	0.40	0.57	0.50
PRICE	23.21	17.98	37.47	33.02
DOMINANT FIRM	0.16	0.37	0.00	0.00
FIRM AWARD	0.20	0.40	0.03	0.17
PATENTS	785.64	2,223.63	171.22	943.01