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AN EMPIRICAL ANALYSIS OF FIRM PRODUCT LINE DECISIONS

ABSTRACT

Despite the importance of product line management as a competitive tool, empirical research addressing the determinants of firm product line decisions is sparse. In this paper, we propose and empirically estimate a descriptive model of firm product line decisions in the personal computer industry over the period 1981-1992. Our model incorporates the firm’s initial choice of the direction of a product line change (i.e., the product line can be expanded, contracted, or maintained) and the conditional choice related to the magnitude of any product line change (i.e., how many products to introduce or withdraw). We show that there are important substantive insights to be gained by analyzing the product line decision in this fashion. In this industry, for example, firms expand their product lines when industry barriers are low or market opportunities are perceived to exist. High market share firms aggressively expand their product lines, as do firms with relatively high prices or short product lines. In general, our results highlight the various internal and external factors that influence firms in managing their product lines.
Product line management is an important tool of competitive strategy used by firms in diverse industries. For example, new product introductions in supermarkets set records in 1994 when over 21,000 new SKUs were launched (McMath 1994). In the beverage category alone, almost two thousand new SKUs are added each year to the 20,000 existing beverage SKUs (Khermouch 1995; Edmunds and McSparran 1996). In the personal computer industry, the number of product models offered for sale in 1992 was over 2,000 (Hays 1994). Experience has also shown that tremendous savings can be achieved from pruning marginal products from a product line (e.g., Kotler 1965; Quelch and Kenny 1994). For example, Procter & Gamble has eliminated a quarter of its entire product line by selling off marginal brands and reducing the varieties of other products (Narisetti 1997). In the personal computer industry, IBM has recently slashed its number of product models over twenty-fold (Narisetti 1998).

In making its product line decisions, a firm facing external market pressures will consider a variety of strategic factors to select the direction of a line length change (e.g., expand, maintain or prune its current product line). For example, consider Masamoto Corporation, a Japanese manufacturer of office equipment who sold a line of daisy-wheel typewriters in the U.S. market in the late 1980’s.¹ Due to an increase in personal computer and stand-alone word processor penetration, Masamoto identified a need to supplement its typewriter line with home word processors – market research suggested that, at the time, 85% of current typewriter owners would consider a home word processor when it became necessary to replace their existing typewriter. Thus, Masamoto initially identified a specific market need and, as a result, decided to expand its product line to include new generation products (the home word processor). More generally, a cost reduction strategy is often associated with a desire to reduce the firm’s product line length, while product line expansion can occur when new markets or customer segments are targeted (Hisrich and Peters 1991; Lehmann and Winer 1997).

¹ Details of this example are discussed in Urban and Hauser (1993, pp. 409-416).
In the case of Masamoto however, the number of new products to be introduced was only decided after a detailed customer segmentation and internal profitability study was conducted. This suggests that any decision regarding the magnitude of a line change depends critically upon (and indeed is conditional on) the firm’s decision to change its product line in the first place. Further, the factors driving the direction decision may be different from those determining the magnitude decision (Easterfield 1964; Murray and Wolfe 1970; Shapiro 1977). Previous research has generally only considered a single dimension of this decision (e.g., the firm’s line extension decision; Reddy, Holak and Bhat 1994). We are unaware of any studies that recognize that a firm’s product line decision involves discrete (i.e., whether or not to make a change) and continuous (i.e., how large a change to make) elements.²

The objective of this paper is to improve our understanding of the firm’s product line decision. To do this, we propose and empirically estimate a descriptive model of the firm’s product line decision. This model incorporates the discrete choice pertaining to the direction of a product line change (i.e., the product line can be expanded, contracted, or maintained) and the continuous choice related to the magnitude of any product line change (i.e., how many products to add or delete). An important conclusion of our research is that different factors influence these two decisions. Given that our emphasis is on firm product line decisions, our research contributes to the existing literature that only considers brand extensions (Smith and Park 1992; Reddy, Holak and Bhat 1994) or consumer responses to product variety (Fader and Hardie 1996; Broniarczyk, Hoyer and McAlister 1998).

Despite its importance, however, our understanding of firm product line decisions is far from complete as very few theoretical and empirical studies on this topic have been published (e.g., see the review by Lancaster 1990 and the comment by Ratchford 1990). In one of the few empirical studies

² Other research has recognized that many choices involve discrete and continuous elements (e.g., Dubin and McFadden 1984; Hanemann 1984; Krishnamurthi and Raj 1988). For example, electricity consumption, a continuous choice, depends upon choice of appliance (e.g., electric or gas), a discrete decision. Stavins (1995) recognizes this point noting that firm product line decisions entail choosing “whether to introduce new product models... and where to locate them...” (p. 571). In her analysis, she addresses the second question, but not the first. Finally, we note that Urban and Hauser (1993) and Clark and Wheelwright (1993) present numerous examples similar to the Masamoto example discussed here.
on this topic, Connor (1981) relates several market structure variables to counts of the number of new products introduced into over one hundred food categories. He finds that product proliferation is positively related to the concentration of sales and advertising intensity, concluding that imperfect market structures generate high levels of product proliferation. Stavins (1995) studies the factors related to product dispersion (defined via a hedonic price analysis) and model exit decisions in the personal computer industry. She finds that the longer a firm has been on the market and the more models it has produced in the past, the more likely it is to spread its products in the quality spectrum. More recently, Bayus and Putsis (1999) empirically consider the demand and supply implications of product proliferation strategies in the personal computer industry. Estimating a simultaneous equations model, they find that product line length is positively related to both demand (share) and supply (price).

Broadly speaking, the limited prior research has identified four distinct influences on firms’ product line length decisions. First, the more heterogeneous a firm’s customer base, the broader the firm’s line needs to be in order to satisfy the needs of its customers (Hauser and Shugan 1983; Brander and Eaton 1984). For example, Stavins (1995) considers the dispersion of each firm’s offerings in attribute space while Schmalensee (1978) examines the impact of attribute position on entry deterrence. Second, the greater the underlying demand for a firm’s products, the greater the marginal profitability of adding additional products to the firm’s existing product line. Thus, variables such as the number of competing models (Stavins 1995), degree of substitutability across products (Lancaster 1990) and relative price (Bayus and Putsis 1999) have all been suggested as ways to operationalize the strength of the underlying demand for a firm’s products. Third, the greater the firm’s ability to raise price above marginal cost due to the industrial organizational structure of the market, the greater the incentive to produce a broader product line (again due to a larger marginal profitability of assortment, see Connor 1991; Shugan 1989; Lancaster 1990 and especially the discussion in Ratchford 1990). Thus, market structure factors such as market share and industry
concentration (Connor 1981; Putsis and Bayus 1999) and direct cost influences such as package size
(Connor 1991; Putsis 1997) have been hypothesized to influence firms line length decisions. Fourth,
strategic considerations can play an important role in decisions to expand or contract a firm’s existing
product line (Brander and Eaton 1984; Lancaster 1990; Ratchford 1990). For example, longer product
lines may be used to deter entry (Schmalensee 1978), raise price (Putsis 1997), or may be indicative
of prior tendencies towards proliferation (Stavins 1995). Thus, variables capturing the size of a firm’s
product line over previous periods (e.g., lagged line length in Stavins 1995) and/or indicating
aggressive prior expansion (e.g., growth rates in Connor 1981) have been used. Unlike the previous
empirical research, we consider all of these influences in the same model. Moreover, our proposed
two-stage model of the firm’s product line length decision allows for richer substantive insights such
as asymmetric effects of variables on the decision to increase versus decrease the line length.
However, it is important to note that the specific variables we consider relate to our specific empirical
application, and accordingly do not represent the exhaustive set of measures suggested by the broader
literature.

The remainder of this paper is organized as follows. To furnish a specific context for our model
development, we discuss the empirical setting for our study in the next section by providing some
background on the personal computer industry and the extent of product proliferation between 1981-
1992. In the following section, we present our descriptive model of the product line decision and
discuss estimation issues. Empirical results are then presented, while implications and conclusions are
discussed in the final section.

THE PERSONAL COMPUTER INDUSTRY

A personal computer can be defined as a general-purpose, single-user machine that is
microprocessor based and can be programmed in a high-level language. Excellent historical reviews
of the personal computer industry are given in Langlois (1992) and Steffens (1994). For our purposes,
information from International Data Corporation’s (IDC) Processor Installation Census (PIC), which
began in 1964, is used. IDC is the oldest among the various firms that tracks the American computer industry and is widely recognized as having a very accurate picture of the activity in this industry.

Our study population includes all firms that sold a personal computer in the United States during the period 1981-1992. Unlike the years before 1981, these twelve years are characterized by rapid expansion in sales (Bayus 1998). During this period, sales grew from under 800,000 units to almost 12 million units in 1992. In addition, the number of competing firms in the market increased from 97 in 1981 to almost 300 by 1992. Technology also improved substantially over this period. For example, the microprocessors\(^3\) used in the first generation personal computers (e.g., Intel’s 8080) were superceded by second generation (e.g., Intel’s 286), third generation (e.g., Intel’s 386), and fourth generation (e.g., Intel’s 486) technology. We note that personal computers from each of these technology generations were in the market contemporaneously throughout the twelve-year period.

During this period, product proliferation is also very evident (Bayus 1998). The number of product models available in the market steadily increased from just over 150 models in 1981 to more than 2,000 different product models in 1992. In addition, the average length of product lines expanded rapidly from under two products in 1981 to almost seven product models in 1992.\(^4\)

In summary, the personal computer industry over this twelve-year period is an excellent setting in which to examine the product line decisions of firms. Firms were generally active in expanding or contracting their product lines. For example, 44 percent of the observations in our data correspond to

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\(^3\) As discussed in Bayus (1998), the most parsimonious way to describe the technology generations among personal computers is to compare their microprocessors or CPUs (central processing unit). The CPU is the brain of the computer since it contains the arithmetic and logic component, as well as the core memory and control unit, for the computer. Thus, CPU design determines the computer’s overall power and performance.

\(^4\) As discussed in Steffens (1994), manufacturers generally use unique model names for personal computers with different CPUs and incur significant expenses with the production and launch of each model. Separate model names for each of the different microprocessor speeds (e.g., 80386 and 80386SX) are also often used. Multiple memory, display, sound, and communication configurations are then typically possible within any model, and can be changed at the time of purchase or later. Thus, our measure of product proliferation is based on unique manufacturer identified product models in the IDC database. See also Bayus (1998).
product line increases and 15 percent to product line decreases. In addition, the mean product line increase was 3.0 product models and the mean decrease was 1.8.

More importantly, detailed data on firms’ product line decisions are available for a large set of competitors over several years. Thus, we can construct annual firm-level data from the detailed product-level information in the original IDC database. Data on a firm’s product line length (i.e., the number of product models offered for sale by a firm in a particular year), and changes in line length over time, are used to develop appropriate measures of the discrete and continuous elements of the product line decision. We also consider several independent variables used in various prior studies and which are available in the IDC database. A summary of these variables, their definitions, and descriptive statistics are contained in Table 1.

[insert Table 1 about here]

MODEL DEVELOPMENT AND ESTIMATION ISSUES

In this section, we propose an empirical framework for a firm’s product line decision. Given the meager empirical research conducted on this topic to date and the limited set of variables that can be constructed from our database, we take an approach that is exploratory in nature. Thus, we do not propose a comprehensive theory of firm product line decisions. Instead, we offer a basic framework for improving our understanding of the firm’s product line decision. We also discuss the econometric issues associated with this descriptive model.

[insert Figure 1 about here]

Figure 1 summarizes the framework that will guide our empirical analysis. We model a firm’s decision to change its product line length to be a function of its perceptions of the strategic opportunities and industry barriers that exist in the market. Conditional on a decision to change its line length, the magnitude of any increase or decrease is modeled as a function of the internal and
external pressures driving the relative profitability of alternative line length decisions. We address the change and magnitude decisions in turn below.

**The Decision of Whether to Change Product Line Length**

We first define $\text{CHANGE}_{it}$ to be an ordered categorical variable representing the three possible product line change decisions for firm $i$ in period $t$ (*i.e.*, $\text{CHANGE}_{it}=0$ if the product line length is decreased, $\text{CHANGE}_{it}=1$ if the product line length is maintained, and $\text{CHANGE}_{it}=2$ if the product line length is increased). According to the framework presented in Figure 1, we define $\text{CHANGE}_{it}$ to be a function, $\Phi$, of several explanatory variables denoted by $\theta_{i}^{t-1}$, which represents a $j$-dimensional vector capturing the various strategic opportunities and industry barriers faced by firm $i$ in period $t-1$. Note that due to development and introduction lags, we assume that each firm’s product line length decision is made at the outset of period $t$, and therefore, depends upon period $t-1$ explanatory variables. Thus, we specify each of the explanatory variables in lagged terms.

Using this definition, we can formulate a standard ordered probit model to represent the firm’s choices regarding the direction of any product line changes (see Maddala 1983, pp. 46-49 or Greene 1997, pp. 926-931):

\[
\begin{align*}
\text{Prob}\{\text{CHANGE}_{it} = 0\} &= \Phi\{-\beta \cdot \theta_{i}^{t-1}\} \\
\text{Prob}\{\text{CHANGE}_{it} = 1\} &= \Phi\{\delta - \beta \cdot \theta_{i}^{t-1}\} - \Phi\{-\beta \cdot \theta_{i}^{t-1}\} \\
\text{Prob}\{\text{CHANGE}_{it} = 2\} &= 1 - \Phi\{\delta - \beta \cdot \theta_{i}^{t-1}\}
\end{align*}
\]

Here, $\Phi$ represents the standard normal distribution, $N(0,1)$, $\beta$ represents a $j$-dimensional vector of parameters to be estimated, and $\delta$ is the (estimated) threshold value for the standard ordered probit with three categories (*e.g.*, see Greene 1997, pp. 926-931).

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5 Aside from being consistent with firm behavior in the industry and previous empirical research in a similar setting (Stavins 1995), we note that this specification also takes care of a number of potential endogeneity issues that may arise in an estimation of this type (*e.g.*, an explanatory variable like $SHARE_{i}^{t-1}$ is predetermined in $t$, whereas $SHARE_{i}^{t}$ is clearly endogenous in period $t$).
In this ordered probit model, we consider several explanatory variables that have been used in prior studies to more broadly explain product line changes. In general, these variables represent external strategic factors that affect the firm’s likelihood of responding to market opportunities or overcoming industry barriers. We specify $\theta_{i,t-1}$ to be a function of the following variables (Table 1, presented earlier, contains descriptive statistics for all variables): \textit{MKTGROWTH} (percentage growth rate in overall industry sales), \textit{PRODENTRY} (the market-wide annual number of new products introduced), \textit{HHI} (the Herfindahl Index of industry concentration), and \textit{SHARE} (the ratio of firm $i$'s total unit sales across its entire product line to total industry sales). We expect that a high market growth rate is related to a greater incentive for all firms to expand their product lines to satisfy the various (growing) consumer segments, and thus the coefficient for \textit{MKTGROWTH} should be positive (e.g., see Lancaster 1990; Quelch and Kenny 1994). \textit{Ceteris paribus}, a higher level of new product introduction activity by competitors should be associated with greater barriers to product line expansion by any individual firm due to an increasingly crowded product space (Schmalensee 1978; Martin 1993, chapter 7). Thus, we expect that the coefficient for \textit{PRODENTRY} will be negative (Brander and Eaton 1984; Bonanno 1987; Lancaster 1990). In addition, a high level of industry concentration (as measured by the Herfindahl Index) should increase the likelihood of a retaliatory competitive response to any new entrant (see, e.g., Clarke, Davies and Waterson 1984; Martin 1993), thereby making it more difficult for any firm to further expand its product line length. Thus, the coefficient for \textit{HHI} is expected to be negative. Since broader product lines are often used as a defensive strategy to protect an achieved market position (Connor 1981; Bhat 1987; Gilbert and Matutes 1993), we also expect that the effects of \textit{SHARE} will be positive.

Finally, based on previous work in this industry setting, we recognize that a firm’s likelihood of responding to market-level opportunities and threats is influenced by its current position in the market (Stavins 1995; Bayus and Putsis 1999). Thus, we also examine two additional variables: \textit{TECHAGE}
(the average age of firm $i$’s product line, weighted by sales, relative to the overall average age of technology on the market) and $FIRMAGE$ (firm $i$’s age). Firms with a relatively “old” product line as compared to the product technology available in the market are expected to be interested in withdrawing some of their products with “old” technology. Since large (small) values of $TECHAGE$ imply that the firm’s product line is older (younger) than that of competing firms, we expect that the coefficient for $TECHAGE$ will be negative. Consistent with general observations (e.g., Shapiro 1977), product lines in the personal computer industry have tended to lengthen over time as the industry has grown. Due to the dynamic nature of technology in this industry, these longer product lines generally contain products with older technologies. Thus, we expect that $FIRMAGE$ will be negatively related to the firm’s line change decision since older firms (that have long product lines with older technologies) will generally be interested in pruning their line.

**The Decision of How Much to Increase or Decrease Product Line Length**

We begin by noting that for each firm $i$ there exists an optimal product line length in each time period $t$, denoted $L^*_{it}$. Consistent with the existing literature (e.g., Easterfield 1964; Murray and Wolfe 1970; Shapiro 1977; Kotler 1997), we assume that $L^*_{it}$ is known by each firm but is not observable to the researcher. We conjecture that the firm’s optimal product line length is affected by a set of variables, $\lambda_{i,t-1}$, representing a $k$-dimensional vector of internal and external factors that influence the profitability of alternative line length decisions (we note that the set of $k$ variables driving the magnitude decision are not necessarily the same set of $j$ variables driving the initial decision to change the line length). Thus, we model the firm’s optimal product line length as: $L^*_{it} = g(\lambda_{i,t-1})$.

To derive the appropriate equations to be estimated for the magnitude decision, we first note that a firm’s decision regarding how much to change its line by is conditional on the decision to change the line in the first place. This has important econometric implications for estimation (as discussed below). Second, we note that $L^*_{it}$ is not observed. What is observable, however, is the actual product line
length for each firm in each time period, $L_{it}$. Defining $\Delta L_{it}$ to be the difference in firm $i$’s product line length between year $t$ and $t-1$, we can make inferences about $L^*_{it}$ in period $t$ relative to the firm’s actual line length in period $t-1$ by examining the change in the firm’s line length from $t-1$ to $t$:

(i) $\Delta L_{it} = \phi_I (L^*_{it} - L_{it-1})$ if the firm decided to increase its product line length

(ii) $|\Delta L_{it}| = \phi_D (L^*_{it} - L_{it-1})$ if the firm decided to decrease its product line length,

where $\phi$ represents the mapping that occurs between desired and actual product line changes. We specify different mapping functions for product line increases ($\phi_I$) and product line decreases ($\phi_D$) to allow for the possibility of asymmetric effects of the explanatory variables on the magnitude decision.

Since $L^*_{it} = g(\lambda_{i,t-1})$, we can write:

(i) $\Delta L_{it} = \phi_I (\lambda_{i,t-1}) + \omega_1$ if the firm decided to increase its product line length

(ii) $|\Delta L_{it}| = \phi_D (\lambda_{i,t-1}) + \omega_2$ if the firm decided to decrease its product line length,

where $\omega_1$ and $\omega_2$ are assumed to be i.i.d. and $N(0,1)$ under an appropriately specified $\lambda_{i,t-1}$ vector.

In the set of equations in (2), we consider several explanatory variables in the $\lambda_{i,t-1}$ vector (see Table 1 for descriptive statistics): SHARE, PRICE (the ratio of firm $i$’s average price, weighted by sales, to the industry weighted-average price), PRODLINE (the ratio of firm $i$’s product line length to the average industry line length), and PHH (firm $i$’s product line concentration index, calculated as the sum of the squares of the product model shares within the firm’s line). Since broader product lines are often used as a defensive strategy to protect an achieved market position (e.g., Connor 1981; Bhat 1987; Gilbert and Matutes 1993), we expect that the effects of SHARE on the magnitude of a product line increase (decrease) will be positive (negative). Further, we know from previous research (Bayus and Putsis 1999) that, ceteris paribus, firms that command a price premium have a greater financial

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6 Following Bayus and Putsis (1999), nominal prices are reported in Table 1 and used in the estimations. We note that there is some ambiguity in the economics literature on the role that real versus nominal prices play in firm decisions (e.g., see Sheshinski and Weiss 1993). An analysis of real prices (nominal prices adjusted by the annual technology sector CPI deflator) produced similar results to those reported in the Empirical Results section below.
incentive to produce long product lines. By broadening it’s product line, a firm that commands a price premium may be able to extend any competitive advantage on their core products to a broader differentiated line (in short, a *ceteris paribus* increase in price results in an increase in $L^*$). Thus, we expect that the effects of *PRICE* on the magnitude of an increase (decrease) in product line length will be positive (negative). Due to diminishing returns associated with longer lines (*e.g.*, Schmalensee 1978; Brander and Eaton 1984; Bayus and Putsis 1999), we expect that the effect of *PRODLINE* on the magnitude of any product line increase will be negative. At the same time, longer product lines generally have more candidates for pruning, suggesting that the effect of *PRODLINE* on the magnitude of product lines decrease will be positive. Finally, since highly concentrated product lines (*i.e.*, most of the firm’s sales are due to relatively few product models) are indicative of a focused niche strategy, we do not expect that such firms would make dramatic changes to the length of their line for fear of cannibalizing existing product sales. Essentially, small players with narrow, well-focused product lines tend not to make dramatic shifts in line length in either direction. Thus, we expect that the effects of *PHHI* on the magnitude of a product line increase *and* decrease are negative.

**Estimation Issues**

As suggested in Figure 1 and the discussion above, the firm’s decision on the magnitude of any product line change is conditional on its line change decision. Essentially, given its existing product line length in period $t-1$, a firm faces two distinct, albeit related, choices regarding the length of its product line in period $t$. First, there is the *discrete* choice pertaining to the *direction* of product line change (*i.e.*, the product line can be expanded, contracted, or maintained). Second, there is the *continuous* choice regarding the *magnitude* of the line change (*i.e.*, the number of products to add or delete). Clearly, the two decisions are inter-related, with the magnitude of the product line change depending on the firm’s decision regarding the direction of any line change. Previous research addressing continuous and discrete choice decisions of this fashion suggests that it is extremely important that “the two choices…be modeled in a mutually consistent manner” (Hanemann 1984, p.
Empirical specifications that ignore this fact will lead to biased and inconsistent parameter estimates (e.g., see Heckman 1979; Dubin and McFadden 1984; Krishnamurthi and Raj 1988). For example, applying OLS directly to Equation (2) is inappropriate econometrically. To see this, note that estimation of the two equations in (2) necessitates splitting the sample into firms that increase their line length (in Equation 2i) and that decrease their line length (in Equation 2ii), respectively. In doing so, we are faced with a classic sample selection problem (Heckman 1979) – the conditional expectations of $\omega_1$ and $\omega_2$ are no longer equal to zero, thereby leading to biased OLS parameter estimates. Thus, appropriate estimation of the magnitude equations in (2) requires using a selection-bias correction factor (which equals the ratio of the PDF to the CDF for the relevant choice in Equation 1) obtained from the first stage probit. This correction factor (denoted by $\mu$) essentially adjusts the $\Delta L$ equations to account for the relevant conditional probabilities and results in zero error expectations. Thus, unbiased estimates of the impact of each independent variable on the magnitude decision in Equation (2) can be obtained via OLS by including $\mu$ as an additional covariate in (2). See Heckman (1979), Greene (1997, pp. 948-956), and in particular Killingsworth (1984, pp. 135-150) for additional discussion of sample selection issues, and Krishnamurthi and Raj (1988) for a discussion of a sample selection instrument in a polychotomous logit model.

To study the product line decisions in the personal computer industry, we analyze data that vary across firms and across time. The time series variation is important to obtain sufficient variability in product line decisions for any particular firm, while cross-sectional nature of the data allows us to also exploit inter-firm variability in product line decisions.7

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7 We also considered alternative stratifications across firms and across technology platforms. For example, we split the full sample by firm size (by quartiles) using a standard likelihood ratio pooling test under the null that the coefficients were equal across the quartiles. In addition, we included binary variables to capture the timing of introduction of each of the new technology generations. In the first case, we could not reject the null ($\alpha=0.05$), while in the second, a nested F-test ($\alpha=0.05$) did not support the full model.
Finally, in estimating the two-equation system (the change and then magnitude equations), we considered both a linear and a logarithmic functional specification for Equation (2). We employed an extension of the J-test for model selection between the linear and log-linear specifications as suggested by MacKinnon, White and Davidson (1983). Under the null hypothesis of a linear specification, we rejected the null at the 0.01 level (see Greene 1997, pp. 459-461 for an overview of this test). Accordingly, a logarithmic (power) functional form is used for Equation (2).

Thus, our estimation proceeds as follows. First, Equation (1) is specified as an ordered probit. Then, the magnitude Equation (2) is estimated using ordinary least squares for the subset of firms that increased their product line (Equation 2i) and for the subset of firms that decreased their product line (Equation 2ii), including the appropriate value of $\mu$ (from Equation 1) as an instrument in each equation as discussed above.

**EMPIRICAL RESULTS**

Estimation results for Equations (1) and (2) are reported in Tables 2 and 3, respectively. Recall that Equation (1) is the ordered probit formulation for the direction of the product line decision from $t-1$ to $t$, while Equation (2) represents the decision for the magnitude of any product line change\(^8\). Overall, these equations provide an excellent fit to the personal computer data. Furthermore, all of the estimated coefficients are in the expected direction (see Figure 1) and are consistent with previous related research in marketing and economics.

[insert Tables 2 and 3 about here]

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\(^8\) We note that the estimated coefficient for $\mu$ in both magnitude equations is not statistically different from 0 employing the “traditional” t-test under the null hypothesis that the coefficient equals 0. It is important to note that in this context, however, there is no a priori reason why a null that $\mu$ equals 0 should be used. As a result, we test for the presence of a sample selection bias using the test suggested by Krishnamurthi and Raj (1988). We note that if such a bias were not present, then OLS estimation of the magnitude equations without $\mu$ would be unbiased and consistent. This test examines the residuals in the CHANGE equation with the residuals in the two magnitude equations (see Krishnamurthi and Raj 1988, p. 8 for the exact test statistic). For both equations, we reject the null of no selectivity bias at $\alpha = 0.01$. We also note that since the t-statistic on the estimated coefficient for $\mu$ is greater than 1 in both magnitude equations, its inclusion can also be justified by a standard nested F-test.
The results reported in Table 2 for the determinants of the direction of a product line change decision (CHANGE) suggest that an increased likelihood of expanding a product line is associated with low levels of market-wide new product activity (PRODENTRY) and low industry concentration (HHI). These results are consistent with the suggestion made earlier that: (i) a higher level of market-wide new product introduction activity produces greater barriers to product line expansion due to an increasingly crowded product space (Schmalensee 1978; Martin 1993, chapter 7) and (ii) a higher level of industry concentration increases the likelihood of a retaliatory competitive response to any new entrant (see, e.g., Clarke, Davies and Waterson 1984; Martin 1993). Thus, our findings imply that firms in the personal computer industry are more likely to expand their product line when product entry barriers are lower.

Earlier we suggested that broader product lines are often used as a defensive strategy to protect an achieved market position (Connor 1981; Bhat 1987; Gilbert and Matutes 1993). Consistent with this assertion, we find that firms with high market share (SHARE) are more likely to increase the number of products offered. In agreement with recent research that suggests that a firm’s response (via a change in its product line offering) to market-level opportunities and threats is influenced by its existing position in the market (Stavins 1995; Bayus 1998), “younger” firms (FIRMAGE) and firms possessing a “newer” product line (TECHAGE) are found to be interested in increasing the number of product models offered. Finally, although the estimated coefficient for MKTGROWTH is not significant at the 0.05 level, its sign is positive as expected (its inclusion can be justified by a nested F-test). Overall, the results for the CHANGE equation suggest that firms in this industry are more likely to expand their product line when market opportunities are perceived and when barriers to expansion are low.

Conditional on the decision to increase its product line length, the results in Table 3 suggest that firms with high market share (SHARE), high relative prices (PRICE), a relatively short product line
(PRODLINE), and sales evenly spread across several product models (PHHI) tend to make large changes in the length of their product line. We note that these results are consistent with our earlier conjectures. For example, we suggested above that due to diminishing returns associated with longer lines (Schmalensee 1978; Brander and Eaton 1984; Bayus and Putsis 1999), the effect of PRODLINE on a product line increase should be negative. In agreement with this, we find that a firm that has a product line that is already relatively broad is less likely to make further large increases in its line.

Given the intuitive results obtained for a firm’s decision regarding the magnitude of line increases, it is interesting to contrast these results with those obtained for the magnitude of line decreases (Equation 2ii). Given a decision to decrease its product line length, the results in Table 3 suggest that firms with a high market share (SHARE), a relatively short product line (PRODLINE), and the majority of sales coming from only a few product models (PHHI) tend to make small changes in their product line length. Taken together, the results for the two magnitude equations imply that any increases in line length by firms with long existing product lines are generally small in magnitude, whereas decreases in line length by firms with long existing product lines are relatively large. This result is intuitively appealing – when firms with long product lines prune their lines, the cut is likely to be relatively dramatic, but there is reduced incentive (due to diminishing returns to line length) for firms with already long product lines to broaden them further. Finally, we note that for both product line increases and product line decreases, firms with narrower, more focused product lines tend not to exhibit dramatic changes in line length in either direction.

Overall, we note that these empirical results are consistent with our general framework and its underlying assumptions (Figure 1)\textsuperscript{10}. Broadly speaking, these results suggest that firms in the personal

\textsuperscript{10} As a point of comparison (\textit{i.e.}, null), we also regressed SHARE, PRICE, PRODLINE, and PHHI on $\Delta L$ (essentially a one-stage model similar in spirit to Connor 1981). Although not reported here, this single equation “naïve” model produces results that run counter to theory and previous research (\textit{e.g.}, the coefficient for PHHI is positive). More importantly, the single equation could not detect asymmetric effects of the type uncovered with the two-stage approach (\textit{e.g.}, the coefficient for SHARE is statistically insignificant in the single equation model). This further highlights the substantive insights to be gained by using the two-stage methodology we propose.
computer industry aggressively expand their product lines when there are perceived revenue opportunities and tend to protect well-entrenched market niches. For the personal computer industry, a firm’s decision to change its product line length is different than its decision on the magnitude of any increase or decrease in line length. This is evident from the different set of explanatory variables that are significantly related to the CHANGE and $\Delta L$ equations in Tables 2 and 3. Additionally, the effects of the internal and external pressures on the magnitude decision are asymmetric for product line increases versus product line decreases (Table 3). Together, these results highlight the importance of the framework used in our study – to fully understand the complexity of product line decisions, it is important to address both the direction and magnitude decisions.

**DISCUSSION AND CONCLUSIONS**

In this paper, we empirically study the determinants of product line decisions in the personal computer industry over the period 1981-1992. Our results indicate that firms in the personal computer industry expand their product lines when there are low industry barriers (e.g., few market-wide new product introductions, low industry concentration) or perceived market opportunities (e.g., due to high market share, recent market entry). High market share firms in this industry aggressively expand their product lines, as do firms with relatively high prices or short existing product lines. In addition, we find that there are important substantive differences between the factors affecting the direction of a product line change (e.g., expand or contract its current line) versus the magnitude of any line change (i.e., how many products to introduce or withdraw).

Our results also highlight the internal and external pressures faced by firms in this industry over this time period. While long, concentrated product lines create internal pressures to keep the firm’s overall line length under control, external pressures encourage firms to offer increasingly broad lines. We speculate that the internal pressures arise from increased costs due to a loss of scale economies, more complex assembly and distribution, etc. (e.g., see Putsis 1997). In addition,
if competitors offer multiple products to a heterogeneous consumer population in a competitive environment, a firm with only one or two products can be placed at a distinct competitive disadvantage. Thus, these pressures suggest that a prisoner’s dilemma situation may exist where all firms may have product lines that are too broad. We note that this seems to be the general environment in the personal computer industry over this time period in which the industry experienced continued growth in sales (e.g., Steffens 1994). These findings, however, may not hold during periods of slow or stagnant industry sales. For example, more recently some firms in the personal computer industry have taken actions to actively prune their product lines (e.g., Carlton 1993; Hays 1994; Narisetti 1998).

Further, we have recently seen changes in the production process for personal computers that may result in a decreasing cost of proliferation, which has the potential to significantly impact the results presented here. For example, some manufacturers such as Dell, Gateway and Compaq are moving to production methods that can still allow manufacturing scale economies in the presence of a broad product line. In addition, firms have recently begun incorporating modular designs and outsourcing production to third-party manufacturers who, in turn, produce computers for a variety of “manufacturers,” including Dell, Compaq and IBM. This enables the third-party manufacturers to enjoy scale economies while also having the demand-side advantages of a broader product line. In such a setting, a lower marginal cost of proliferation would be expected to exert a positive impact on overall line lengths. More generally, changes in cost structure resulting from broader product lines must be balanced against any associated changes in demand (Bayus and Putsis 1999).

As is the case with all research, our findings should not be generalized beyond the industry, time period, and measures we study. These limitations, however, suggest a number of directions for future research. For example, future studies might attempt to generalize our results to other industry settings (e.g., including dynamic as well as stable product technologies). The impact of other explanatory variables on firm product line decisions can also be empirically explored. For example, information
on product attributes can be used to examine the effects of changes in quality and product positioning strategies over time. Finally, we believe that future research should attempt to extend our understanding of the different factors that affect the direction and magnitude of product line decisions. A study of managers and their perceptions of the critical factors related to their own product line decisions may provide some valuable insights in this area.
REFERENCES


Figure 1
The Empirical Framework for Firm Product Line Decisions

if decision is to increase product line length

MAGNITUDE of Product Line Increase

if decision is to decrease product line length

MAGNITUDE of Product Line Decrease

Strategic Factors
+ Market Growth
- Market-Wide New Product Activity
- Industry Concentration
+ Market Share
- Relative Technological Age of the Firm’s Product Line
- Firm Age

CHANGE the Length of the Product Line
• Increase
• Maintain
• Decrease

Internal and External Pressures
+ Market Share -
+ Relative Price -
- Relative Product Line Length +
- Product Line Concentration -
### Table 1
Variable Definitions and Descriptive Statistics

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Variable Definition</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MKTGROWTH</strong></td>
<td>Percentage growth rate in total industry sales</td>
<td>0.26</td>
<td>0.59</td>
</tr>
<tr>
<td><strong>PRODENTRY</strong></td>
<td>Number of market-wide new product models introduced</td>
<td>372.5</td>
<td>205.7</td>
</tr>
<tr>
<td><strong>HHI</strong></td>
<td>Herfindahl index of industry concentration</td>
<td>0.0739</td>
<td>0.0399</td>
</tr>
<tr>
<td><strong>SHARE</strong></td>
<td>Market share (units) for firm $i$</td>
<td>0.0076</td>
<td>0.0279</td>
</tr>
<tr>
<td><strong>TECHAGE</strong></td>
<td>Difference between the average age of firm $i$’s product line (weighted by sales) to the industry weighted-average age of all products on the market</td>
<td>-2.95</td>
<td>3.96</td>
</tr>
<tr>
<td><strong>FIRMAGE</strong></td>
<td>Firm $i$’s age (in years)</td>
<td>4.81</td>
<td>3.19</td>
</tr>
<tr>
<td><strong>PRICE</strong></td>
<td>Ratio of the average price of firm $i$’s product line (weighted by sales) to the industry weighted-average price</td>
<td>1.45</td>
<td>1.49</td>
</tr>
<tr>
<td><strong>PRODLINE</strong></td>
<td>Ratio of firm $i$’s product line length to the average industry line length</td>
<td>1.24</td>
<td>1.03</td>
</tr>
<tr>
<td><strong>PHHI</strong></td>
<td>Firm $i$’s product line concentration index</td>
<td>0.5628</td>
<td>0.2884</td>
</tr>
</tbody>
</table>
### Table 2
Maximum Likelihood Estimation Results of the Probit Model for the CHANGE decision

**Dependent Variable: CHANGE**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>z = b/s.e.</th>
<th>P[Z&gt;z]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MKTGROWTH</td>
<td>0.134</td>
<td>0.089</td>
<td>1.515</td>
<td>0.129</td>
</tr>
<tr>
<td>PRODENTRY</td>
<td>-0.557E-03</td>
<td>0.270E-03</td>
<td>-2.061</td>
<td>0.039</td>
</tr>
<tr>
<td>HHI</td>
<td>-4.946</td>
<td>1.625</td>
<td>-3.044</td>
<td>0.002</td>
</tr>
<tr>
<td>SHARE</td>
<td>3.473</td>
<td>1.167</td>
<td>2.975</td>
<td>0.003</td>
</tr>
<tr>
<td>TECHAGE</td>
<td>-0.193E-01</td>
<td>0.952E-02</td>
<td>-2.029</td>
<td>0.042</td>
</tr>
<tr>
<td>FIRMAGE</td>
<td>-0.244E-01</td>
<td>0.114E-01</td>
<td>-2.136</td>
<td>0.033</td>
</tr>
<tr>
<td>δ</td>
<td>1.192</td>
<td>0.517E-01</td>
<td>23.040</td>
<td>0.000</td>
</tr>
<tr>
<td>Constant</td>
<td>1.620</td>
<td>0.220</td>
<td>7.368</td>
<td>0.000</td>
</tr>
</tbody>
</table>

LL = -1025.5

χ² = 24.2 (p=0.000)

Number of Observations = 1025

Note: All independent variables are lagged.
Table 3
OLS Estimation Results for the MAGNITUDE Decisions

**Dependent Variable: $\Delta L$ (Increase Product Line Length)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>t-ratio</th>
<th>P[Z&gt;z]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHARE</td>
<td>0.129</td>
<td>0.201E-01</td>
<td>6.420</td>
<td>0.000</td>
</tr>
<tr>
<td>PRICE</td>
<td>0.108</td>
<td>0.500E-01</td>
<td>2.155</td>
<td>0.032</td>
</tr>
<tr>
<td>PRODLINE</td>
<td>-0.232</td>
<td>0.753E-01</td>
<td>-3.078</td>
<td>0.002</td>
</tr>
<tr>
<td>PHHI</td>
<td>-0.642</td>
<td>0.847E-01</td>
<td>-7.589</td>
<td>0.000</td>
</tr>
<tr>
<td>$\mu$</td>
<td>-1.484</td>
<td>1.299</td>
<td>-1.142</td>
<td>0.254</td>
</tr>
<tr>
<td>Constant</td>
<td>4.186</td>
<td>2.801</td>
<td>1.495</td>
<td>0.136</td>
</tr>
</tbody>
</table>

R$^2 = 0.29$; F = 37.39 (p=0.000)
Number of Observations = 455
Note: All variables are expressed in LN form and all independent variables are lagged.

**Dependent Variable: $|\Delta L|$ (Decrease Product Line Length)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>t-ratio</th>
<th>P[Z&gt;z]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHARE</td>
<td>-0.584E-01</td>
<td>0.228E-01</td>
<td>-2.563</td>
<td>0.011</td>
</tr>
<tr>
<td>PRICE</td>
<td>-0.203E-01</td>
<td>0.600E-01</td>
<td>-0.339</td>
<td>0.735</td>
</tr>
<tr>
<td>PRODLINE</td>
<td>0.428</td>
<td>0.945E-01</td>
<td>4.527</td>
<td>0.000</td>
</tr>
<tr>
<td>PHHI</td>
<td>-0.262</td>
<td>0.886E-01</td>
<td>-2.961</td>
<td>0.004</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.409</td>
<td>0.308</td>
<td>1.326</td>
<td>0.187</td>
</tr>
<tr>
<td>Constant</td>
<td>0.160</td>
<td>0.525</td>
<td>0.306</td>
<td>0.760</td>
</tr>
</tbody>
</table>

R$^2 = 0.27$; F = 10.93 (p=0.000)
Number of Observations = 155
Note: All variables are expressed in LN form and all independent variables are lagged.