WILLIAM P. PUTSIS JR. and BARRY L. BAYUS*

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 article, the authors propose and empirically estimate a descriptive model of firm product line decisions in the personal computer industry over the period 1981–92. The 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). The authors show that there are important substantive insights to be gained by analyzing the product line decision in this fashion. In the personal computer 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, the results highlight the various internal and external factors that influence firms' management of their product lines.

An Empirical Analysis of Firms' Product Line Decisions

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 more than 21,000 new stockkeeping units (SKUs) were launched (McMath 1994). In the beverage category alone, almost 2000 new SKUs are added each year to the 20,000 existing beverage SKUs (Edmunds and McSparran 1996; Khermouch 1995). In the personal computer industry, the number of product models offered for sale in 1992 was more than 2000 (Hays 1994). Experience has also shown that tremendous savings can be achieved by pruning marginal products from a product line (e.g., Kotler 1965; Quelch and Kenny 1994). For example, Procter & Gamble has eliminated one-fourth of its entire product line by selling off marginal brands and reducing the varieties of other products (Narisetii 1997). In the personal computer industry, IBM has recently slashed its number of product models more than twentyfold (Narisetii 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 (i.e., expand, maintain, or prune its current product line). For example, consider Masamoto Corporation, a Japanese manufacturer of office equipment that sold a line of daisy-wheel typewriters in the U.S. market in the late 1980s.1 Because of 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, whereas product line expansion can occur when new markets or customer segments are targeted (Hisrich and Peters 1991; Lehmann and Winer 1997).

In the case of Masamoto however, the number of new products to be introduced was decided only after a detailed customer segmentation and internal profitability study was conducted. This suggests that any decision regarding the

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1Details of this example are discussed by Urban and Hauser (1993, pp. 409–16).
magnitude of a line change depends critically (and indeed is conditional) on the firm’s decision to change its product line in the first place. Furthermore, 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 generally has 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 article is to improve the 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 considers only brand extensions (Reddy, Holak, and Bhat 1994; Smith and Park 1992) or consumer responses to product variety (Broniarczyk, Hoyer, and McAlister 1998; Fader and Hardie 1996).

Despite its importance, however, our understanding of firm product line decisions is far from complete, as 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 on this topic, Connor (1981) relates several market structure variables to counts of the number of new products introduced into more than 100 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 through 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 Putis (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 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 (Brander and Eaton 1984; Hauser and Gaskin 1984). For example, Stavins (1995) considers the dispersion of each firm’s offerings in attribute space, and Schmalensee (1978) examines the impact of attribute position on entry deterrence. Second, the greater the underlying demand for a firm’s products, the greater is the marginal profitability of adding 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 Putis 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 is the incentive to produce a broader product line (again, due to a larger marginal profitability of assortment; see Connor 1981; Lancaster 1990; Shugan 1989; and especially the discussion in Ratchford 1990). Thus, market structure factors such as market share and industry concentration (Bayus and Putis 1999; Connor 1981) and direct cost influences such as package size (Connor 1981; Putis 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) or raise price (Putis 1997) or may be indicative of prior tendencies toward proliferation (Stavins 1995). Thus, variables capturing the size of a firm’s product line over previous periods (e.g., lagged line length; Stavins 1995) and/or indicating aggressive prior expansion (e.g., growth rates; Connor 1981) have been used. Unlike the previous empirical research, we consider all 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 article 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 and 1992. In the following section, we present our descriptive model of the product line decision and discuss estimation issues. We then present empirical results, and we discuss implications and conclusions 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 by Langlois (1992) and Steffens (1994). For our purposes, information from International Data Corporation’s (IDC’s) Processor Installation Census, which began in 1964, is
used. Among the various firms that track the U.S. computer industry, IDC is the oldest and is widely recognized as having an 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 1981–92. Unlike the years before 1981, these 12 years are characterized by rapid expansion in sales (Bayus 1998). During this period, sales grew from less than 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 used in the first-generation personal computers (e.g., Intel's 8080) were superseded 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 12-year period.

During this period, product proliferation is also evident (Bayus 1998). The number of product models available in the market steadily increased from slightly more than 150 models in 1981 to more than 2000 different product models in 1992. In addition, the average length of product lines expanded rapidly from less than two products in 1981 to almost seven product models in 1992.

In summary, the personal computer industry over this 12-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% of the observations in our data correspond to product line increases, and 15% to product line decreases. In addition, the mean product line increase was 3.0 product models, and the mean decrease was 1.8.

More important, 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. We use 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 to develop appropriate measures of the discrete and continuous elements of the product line decision. We also consider several independent variables that have been used in various prior studies and that are available in the IDC database. A summary of these variables, their definitions, and descriptive statistics is contained in Table 1.

**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 the understanding of the firm’s product line decision. We also discuss the econometric issues associated with this descriptive model.

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 subsequently.

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

We first define CHANGE	extsubscript{it} to be an ordered categorical variable representing the three possible product line change decisions for Firm i in period t (i.e., CHANGE	extsubscript{it} = 0 if the product line length is maintained, and CHANGE	extsubscript{it} = 1 if the product line length is increased). According to the framework presented in Figure 1, we define CHANGE	extsubscript{it} to be a

<table>
<thead>
<tr>
<th>Table 1</th>
<th>VARIABLE DEFINITIONS AND DESCRIPTIVE STATISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Name</td>
<td>Variable Definition</td>
</tr>
<tr>
<td>MKTGROWTH</td>
<td>Percentage growth rate in total industry sales</td>
</tr>
<tr>
<td>PRODENTRY</td>
<td>Number of marketwide new product models introduced</td>
</tr>
<tr>
<td>HHI</td>
<td>Herfindahl index of industry concentration</td>
</tr>
<tr>
<td>SHARE</td>
<td>Market share (units) for Firm i</td>
</tr>
<tr>
<td>TECHAGE</td>
<td>Difference between the average age of Firm i’s product line (weighted by sales) and the industry weighted-average age of all products on the market</td>
</tr>
<tr>
<td>FIRMAGE</td>
<td>Firm i’s age (in years)</td>
</tr>
<tr>
<td>PRICE</td>
<td>Ratio of the average price of Firm i’s product line (weighted by sales) to the industry weighted-average price</td>
</tr>
<tr>
<td>PRODLINE</td>
<td>Ratio of Firm i’s product line length to the average industry line length</td>
</tr>
<tr>
<td>PPHHI</td>
<td>Firm i’s product line concentration index</td>
</tr>
</tbody>
</table>

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function, $\Phi$, of several explanatory variables denoted by $\Theta_{-1}^t$, which represents a j-dimensional vector that captures the various strategic opportunities and industry barriers faced by Firm i in period $t-1$. Note that because of 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 on 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 Greene 1997, pp. 926–31; Maddala 1983, pp. 46–49):

1. $\text{Prob}(\text{CHANGE}_{it} = 0) = \Phi(-\beta'\delta_{t-1})$.
2. $\text{Prob}(\text{CHANGE}_{it} = 1) = \Phi(\delta - \beta'\delta_{t-1}) - \Phi(-\beta'\delta_{t-1})$, and
3. $\text{Prob}(\text{CHANGE}_{it} = 2) = 1 - \Phi(\delta - \beta'\delta_{t-1})$.

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. 926–31).

In this ordered probit model, we consider several explanatory variables that have been used in prior studies to explain product line changes more broadly. 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 $\theta^{-1}$ to be a function of the following variables (Table 1 contains descriptive statistics for all variables): MKTGRTH (percentage growth rate in overall industry sales), PRODENTRY (the marketwide annual number of new products introduced), HHI (the Herfindahl index of industry concentration), and 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 MKTGRTH should be positive (e.g., see Lancaster 1990; Quelch and Kenny 1994). 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 (Martin 1993, Ch. 7; Schmalensee
Therefore, we expect that the coefficient for PRODENTRY will be negative (Bonanno 1987; Brander and Eaton 1984; 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 expand its product line length further. Therefore, the coefficient for HHI is expected to be negative. Because broader product lines often are used as a defensive strategy to protect an achieved market position (Bhat 1987; Connor 1981; Gilbert and Matutes 1993), we also expect that the effects of SHARE will be positive.

Finally, on the basis of 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 (Bayus and Putsis 1999; Stavins 1995). Therefore, we also examine two additional variables: 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 compared with the product technology available in the market are expected to be interested in withdrawing some of their products with old technology. Because 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. Because of the dynamic nature of technology in this industry, these longer product lines generally contain products with older technologies. Therefore, we expect that FIRMAGE will be negatively related to the firm's line change decision, because older firms (that have long product lines with older technologies) will generally be interested in pruning their lines.

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 \( L^*_i \). Consistent with the existing literature (e.g., Easterfield 1964; Kotler and Mangan 1987; Shapiro 1977), we assume that \( L^*_i \) 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, \( \lambda_i^{k-1} \), 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 is 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 \( L^*_i = g(\lambda_i^{k-1}) \).

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 subsequently). Second, we note that \( L^*_i \) 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 \( L^*_i \) 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:

\[
\Delta L_{it} = \phi_1 (L^*_i - L_{it-1})
\]

if the firm decided to increase its product line length, and

\[
|\Delta L_{it}| = \phi_0 (L^*_i - L_{it-1})
\]

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 (\( \phi_1 \)) and product line decreases (\( \phi_0 \)) to allow for the possibility of asymmetric effects of the explanatory variables on the magnitude decision. Because \( L^*_i = g(\lambda_i^{k-1}) \), we can write

\[
\Delta L_{it} = \phi_1 (\lambda_i^{k-1}) + \omega_1
\]

if the firm decided to increase its product line length, and

\[
|\Delta L_{it}| = \phi_0 (\lambda_i^{k-1}) + \omega_2
\]

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 \( \lambda_i^{k-1} \) vector.

In Equation 3, we consider several explanatory variables in the \( \lambda_i^{k-1} \) vector (for descriptive statistics, see Table 1): 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 PHHI (Firm i's product line concentration index, calculated as the sum of the squares of the product model shares within the firm's line). Because broader product lines are often used as a defensive strategy to protect an achieved market position (e.g., Bhat 1987; Connor 1981; Gilbert and Matutes 1993), we expect that the effects of SHARE on the magnitude of a product line increase (decrease) will be positive (negative). Furthermore, we know from previous research (Bayus and Putsis 1999) that, ceteris paribus, firms that command a price premium have a greater financial incentive to produce long product lines. By broadening its product line, a firm that commands a price premium may be able to extend any competitive advantage on its core products to a broader differentiated line (in short, ceteris paribus, an increase in price results in an increase in \( L^* \)). Therefore, we expect that the effects of PRICE on the magnitude of an increase (decrease) in product line length will be positive (negative). Because of diminishing returns associated with longer lines (e.g., Bayus and Putsis 1999; Brander and Eaton 1984; Schmalensee 1978), 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, which suggests that the effect of PROD-
LINE on the magnitude of a product line decrease will be positive. Finally, because 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 lines 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. Therefore, 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 previous discussion, 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). The two decisions are interrelated: The magnitude of the product line change depends 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. 541). Empirical specifications that ignore this will lead to biased and inconsistent parameter estimates (e.g., see Dubin and McFadden 1984; Heckman 1979; Krishnamurthi and Raj 1988).

For example, applying ordinary least squares (OLS) directly to Equation 3 is inappropriate econometrically. To understand this, note that estimation of the two equations in Equation 3 necessitates splitting the sample into firms that increase their line length (in Equation 3a) and those that decrease their line length (in Equation 3b). 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, which thereby leads to biased OLS parameter estimates. Thus, appropriate estimation of the magnitude equations in Equation 3 requires using a selection bias correction factor (which equals the ratio of the population density function to the cumulative density function 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 3 can be obtained through OLS by including \( \mu \) as an additional covariate in Equation 3. See Heckman's (1979), Greene's (1997, pp. 948-56), and in particular, Killingsworth's (1984, pp. 135-150) work for additional discussion of sample selection issues, and see Krishnamurthi and Raj's (1988) study 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, and the cross-sectional nature of the data enables us also to exploit interfirm variability in product line decisions.\(^7\)

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 3. 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 .01 level (for an overview of this test, see Greene 1997, pp. 459-61). Accordingly, a logarithmic (power) functional form is used for Equation 3.

Thus, our estimation proceeds as follows: Equation 1 is specified as an ordered probit. Then, the magnitude Equation 3 is estimated by means of OLS for the subsets of firms that increased (Equation 3a) and decreased (Equation 3b) their product lines, including the appropriate value of \( \mu \) (from Equation 1) as an instrument in each equation as discussed previously.

**EMPIRICAL RESULTS**

Estimation results for Equations 1 and 3 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 \( t \), and Equation 3 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 the estimated coefficients are in the expected direction (see Figure 1) and are consistent with previous related research in marketing and economics.

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 marketwide new product activity (PRODENTRY) and low industry concentration (HHI).\(^9\) These results are consistent with the suggestion made previously that (1) a higher level of marketwide new product introduction activity produces greater barriers to

\(^7\)We also considered alternative stratifications across firms and technology platforms. For example, we split the full sample by firm size (by quartiles) using a standard likelihood ratio pooling test under the null hypothesis 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 (\( \alpha = .05 \)), and in the second, a nested F-test (\( \alpha = .05 \)) did not support the full model.

\(^8\)We note that the estimated coefficient for \( \mu \) in both magnitude equations is not statistically different from 0 when we employ the traditional t-test under the null hypothesis that the coefficient equals 0. However, it is important to note that in this context, there is no a priori reason that a null hypothesis that \( \mu = 0 \) 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, 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 (for the exact test statistic, see Krishnamurthi and Raj 1988, p. 8). For both equations, we reject the null hypothesis of no selection bias at \( \alpha = .10 \). We also note that because 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.

\(^9\)Note that for the ordered probit in Table 2, we present the estimated coefficients, not the marginal effects.
product line expansion because of an increasingly crowded product space (Martin 1993, Ch. 7; Schmalensee 1978) and (2) 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 lines when product entry barriers are lower.

Previously, we suggested that broader product lines are often used as a defensive strategy to protect an achieved market position (Bhat 1987; Connor 1981; 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 (through a change in its product line offering) to market-level opportunities and threats is influenced by its existing position in the market (Bayus 1998; Stavins 1995), 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 .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 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 previous conjectures. For example, we suggested that because of diminishing returns associated with longer lines (Bayus and Putis 1999; Brander and Eaton 1984; Schmalensee 1978), the effect of PRODLINE on a product line increase should be negative. In agreement with this, we find that a firm with 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 firms’ decisions regarding the magnitude of line increases, it is interesting to contrast these results with those obtained for the magnitude of line decreases (Equation 3b). Given a decision to decrease product line length, the results in Table 3 suggest that firms with a high market share (SHARE), a relatively short prod-

**Table 2**

MAXIMUM LIKELIHOOD ESTIMATION RESULTS OF THE PROBIT MODEL FOR THE CHANGE DECISION

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>z = b/Standard Error</th>
<th>P[Z &gt; z]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MKTGROWTH</td>
<td>.134</td>
<td>.089</td>
<td>1.515</td>
<td>.129</td>
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<tr>
<td>PRODENTRY</td>
<td>-.557E-03</td>
<td>.270E-03</td>
<td>-2.061</td>
<td>.039</td>
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<tr>
<td>HHI</td>
<td>-.946</td>
<td>1.625</td>
<td>-3.044</td>
<td>.002</td>
</tr>
<tr>
<td>SHARE</td>
<td>3.473</td>
<td>1.167</td>
<td>2.975</td>
<td>.003</td>
</tr>
<tr>
<td>TECHAGE</td>
<td>-.193E-01</td>
<td>.952E-02</td>
<td>-2.029</td>
<td>.042</td>
</tr>
<tr>
<td>FIRMAGE</td>
<td>-.244E-01</td>
<td>.114E-01</td>
<td>-2.136</td>
<td>.033</td>
</tr>
<tr>
<td>δ</td>
<td>1.192</td>
<td>.517E-01</td>
<td>23.040</td>
<td>.000</td>
</tr>
<tr>
<td>Constant</td>
<td>1.620</td>
<td>.220</td>
<td>7.368</td>
<td>.000</td>
</tr>
</tbody>
</table>

Notes: Dependent variable = CHANGE. Log-likelihood = -1025.5. χ² = 24.2 (p = .000). Number of observations = 1025. All independent variables are lagged.

**Table 3**

OLS ESTIMATION RESULTS FOR THE MAGNITUDE DECISIONS

**A: Dependent Variable: ΔL (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>.129</td>
<td>201E-01</td>
<td>6.420</td>
<td>.000</td>
</tr>
<tr>
<td>PRICE</td>
<td>.108</td>
<td>500E-01</td>
<td>2.155</td>
<td>.032</td>
</tr>
<tr>
<td>PRODLINE</td>
<td>-.232</td>
<td>735E-01</td>
<td>-3.078</td>
<td>.002</td>
</tr>
<tr>
<td>PHHI</td>
<td>-.642</td>
<td>847E-01</td>
<td>-7.589</td>
<td>.000</td>
</tr>
<tr>
<td>δ</td>
<td>-.1484</td>
<td>1.299</td>
<td>-1.142</td>
<td>.254</td>
</tr>
<tr>
<td>Constant</td>
<td>4.186</td>
<td>2.801</td>
<td>1.495</td>
<td>.136</td>
</tr>
</tbody>
</table>

**B: Dependent Variable: |ΔL| (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>-.584E-01</td>
<td>228E-01</td>
<td>-2.563</td>
<td>.011</td>
</tr>
<tr>
<td>PRICE</td>
<td>-.203E-01</td>
<td>600E-01</td>
<td>-3.39</td>
<td>.735</td>
</tr>
<tr>
<td>PRODLINE</td>
<td>.428</td>
<td>945E-01</td>
<td>4.527</td>
<td>.000</td>
</tr>
<tr>
<td>PHHI</td>
<td>-.262</td>
<td>886E-01</td>
<td>-2.961</td>
<td>.004</td>
</tr>
<tr>
<td>μ</td>
<td>.409</td>
<td>.308</td>
<td>1.326</td>
<td>.187</td>
</tr>
<tr>
<td>Constant</td>
<td>.160</td>
<td>.525</td>
<td>.306</td>
<td>.760</td>
</tr>
</tbody>
</table>

aR² = .29, F = 37.39 (p = .000). Number of observations = 455.
bR² = .27, F = 20.93 (p = .000). Number of observations = 155.

Notes: All variables are expressed in natural log form, and all independent variables are lagged.
product line (PRODLINE), and the majority of sales coming from only a few product models (PHHII) 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).10 Broadly speaking, these results suggest that firms in the personal 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 from its decision on the magnitude of any increase or decrease in line length. This is evident from the different set of explanatory variables that is significantly related to the CHANGE and ΔL equations in Tables 2 and 3. In addition, 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 understand the complexity of product line decisions fully, it is important to address both the direction and the magnitude decisions.

DISCUSSION AND CONCLUSIONS

In this article, we empirically study the determinants of product line decisions in the personal computer industry over the period 1981–92. Our results indicate that firms in the personal computer industry expand their product lines when there are low industry barriers (e.g., few marketwide 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 (i.e., expand or contract its current line) and 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.

Although 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, and so forth (e.g., see Putis 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, in which 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 prune their product lines (e.g., Carlton 1993; Hays 1994; Narisseti 1998).

Furthermore, recently there have been changes in the production process for personal computers that may result in a decreasing cost of proliferation, which has the potential to affect the results presented here significantly. For example, some manufacturers, such as Dell, Gateway, and Compaq, are moving to production methods that still allow manufacturing scale economies in the presence of a broad product line. In addition, firms recently have begun incorporating modular designs and outsourcing production to third-party manufacturers that, 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 Putis 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 several directions for further 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 also can 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 further research should attempt to extend the 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 product line decisions may provide some valuable insights in this area.

REFERENCES


10As a point of comparison (i.e., null), we also regressed SHARE, PRICE, PRODLINE, and PHHII on ΔL (essentially a one-stage model similar in spirit to Connor’s [1981]). Although not reported here, this single-equation “naive” model produces results that run counter to theory and previous research (e.g., the coefficient for PHHII is positive). More important, the single equation could not detect asymmetric effects of the type uncovered with the two-stage approach (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.