Product Proliferation: An Empirical Analysis of Product Line Determinants and Market Outcomes

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Abstract

Considering the number of new product introductions and available product varieties today, the practice of product proliferation is visibly evident in many diverse industries. Given its prevalence in practice, understanding the determinants and implications of firm proliferation strategies clearly has important managerial relevance.

Previous theoretical research has identified three primary effects of a proliferation strategy: (1) a broad product line can increase the overall demand faced by the firm, (2) a broad product line can affect supply by increasing costs, and (3) broad product lines can have strategic consequences (e.g., long product lines can deter entry, thereby allowing an incumbent firm to raise prices). However, despite the theoretical interest in this common business practice, there has been very little empirical research on this topic. Moreover, no empirical study has simultaneously considered all three of the possible effects associated with a proliferation strategy. Consequently, in this paper we propose a three-equation simultaneous system that captures both the determinants and market outcomes of a firm's product line decisions. In particular, we specify market share, price, and product line length equations, which are estimated by three stage least squares. Using this structure, we empirically study the personal computer industry over the period 1981–1992.

Our empirical results demonstrate that proliferation strategies do not have a uni-dimensional explanation. We find that product proliferation decisions have both demand (market share) and supply (price) implications. Our empirical results also suggest that the firm-level net market share impact of product proliferation in the personal computer industry is negative (i.e., the cost increases associated with a broader product line dominate any potential demand increases). As expected, we find that structural competitive factors play an important role in the determinants and market outcomes of a firm's product line decisions. However, we do not find evidence of firms using proliferation strategies to deter entry in this industry. Finally, we also demonstrate that some of the empirical conclusions from previous research are reversed once product line length is specified as endogenous in the share and price specifications.

(*Product Proliferation*; *Product Line Pricing*; *Entry Deterrence*; *Personal Computer Industry*)

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1. Introduction

Product proliferation is an important tool of competitive strategy used by firms in diverse industries. As discussed by Connor (1981), indicators of product proliferation include a large number of new product introductions, wide product variety, and long product lines. Today, the practice of product proliferation is clearly evident.[1] For example, in 1994 new product introductions in supermarkets set records 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). Crest and Colgate each have more than 35 types of toothpaste (Quelch and Kenny 1994), and Head & Shoulders dandruff shampoo has 15 different varieties (Narisetti 1997). Moreover, product proliferation is not restricted to the supermarket, as companies like Goodyear Tire & Rubber, Gillette, and Eastman Kodak have all recently increased the length of their product lines (Stern 1992). Product line proliferation is also particularly evident in technologically dynamic industries such as personal computers; for example, in 1992 there were over 2,000 different PC models available in the market (e.g., McCartney 1993, Pope 1993, Hays 1994, Ziegler 1995).

Previous research, largely theoretical in nature, has identified three mechanisms by which proliferation strategies can affect individual firm conduct and market equilibria (e.g., see the review by Lancaster (1990) and commentary by Ratchford (1990)). On the demand side, a broad product line can allow a firm to satisfy the needs and wants of heterogeneous consumers more precisely (e.g., Shapiro 1977, Lancaster 1979, Connor 1981, Quelch and Kenny 1994). Consequently, product proliferation can increase the overall demand faced by the firm. On the supply side, a broad product line will increase the firm's per unit production costs when scale economies are present (e.g., Baumol et al. 1982). In addition, a broad product line may lead to added design costs, additional inventory holding costs, and added complexity in the assembly process (e.g., Lancaster 1979, 1990; Moorthy 1984). Thus, in making its product line decisions, a firm must balance any demand increases due to proliferation with the associated increases in costs. Finally, external strategic considerations can also play an important role in individual firm proliferation strategies. For example, broad product lines in oligopolistic markets can deter entry (e.g., Schmalensee 1978, Brander and Eaton 1984, Bonanno 1987), thereby allowing an incumbent firm to raise its market prices (e.g., Benson 1990, Levy and Reitzes 1993, Putsis 1997). Similarly, a long product line can be used as a defensive strategy to protect against a proliferating competitor (e.g., Bhat 1987, Gilbert and Matutes 1993) or to enhance firm reputation (e.g., Womack et al. 1990, Moorthy and Papatla 1998). Recent related research in marketing has focused on distribution issues (Villas-Boas 1998) and price expectations (Balachander and Srinivasan 1998).

Despite the theoretical interest in this common business practice, however, there has been very little empirical research addressing the determinants and implications of firm proliferation strategies (Lancaster 1990, Ratchford 1990). Moreover, no empirical study has simultaneously considered all three of the possible effects associated with a proliferation strategy (i.e., demand, supply, and strategic considerations such as entry deterrence). Instead, the limited empirical work to date has essentially taken a "reduced form" approach by attempting to *assess* the net impact of proliferation strategies. For example, Kekre and Srinivasan (1990) find that product line length is positively related to share (which in turn is positively related to ROI), while Putsis (1997) finds that an increase in the number of brands increases the ability of national brand manufacturers to raise price.

However, as the discussion above suggests, any unidimensional explanation of the impact of proliferation strategies is likely to be incomplete. Consequently, in this paper we attempt to provide a unified empirical framework that captures both the determinants and market outcomes of product line decisions for firms in the personal computer industry from 1981–1992. In doing so, we note that this approach is consistent with

[1] It is interesting to note that this is not really a new strategy. In June 1955, Grey Advertising's newsletter stated "... the stream of new products and new variations of old products which is being forced down the consumer's throat is so swollen that there is great danger of indigestion..." (Alsop 1995). See also *Time* (1958).

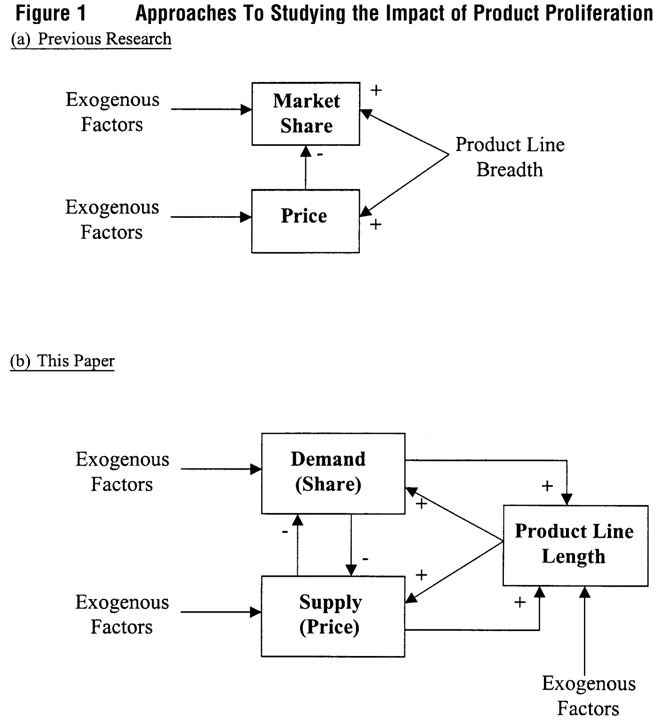
Shocker et al.'s (1994) call for future product line research to be more "integrative" in nature.

Although we build on prior efforts, our research approach is distinct from existing work. First, we study the performance effects associated with an *objective* measure of product proliferation (the number of products in a firm's product line). This is in contrast to the PIMS studies that analyze subjective self-reported data on relative product line breadth (e.g., Robinson and Fornell 1985, Robinson 1988, Kekre and Srinivasan 1990), and the related brand extension research which does not specifically consider the effects of product line proliferation (e.g., Smith and Park 1992, Sullivan 1992, Reddy et al. 1994). Second, unlike much of the prior empirical literature, we incorporate developments in the industrial organization literature on differentiated products which suggests that both share and price are not only endogenously determined, but also influenced by the structural characteristics (e.g., concentration) of the market (e.g., Deneckere and Davidson 1985, Willig 1991). Third, we consider a simultaneous model in which market share, price, *and* product line length are specified as *jointly endogenous.* Thus, as illustrated in Figure 1, our research differs from prior studies in that we estimate a "complete" *three-equation system* that captures the market outcomes as well as the determinants of a firm's product line decisions.[2]

The remainder of this paper is organized as follows. In the next section, we review the limited empirical literature that addresses product proliferation. We then provide some background on the personal computer industry and the extent of product proliferation between 1981–1992. Next, we present our general model addressing the determinants and market outcomes of a firm's product line decisions. We also discuss the key hypotheses to be examined and give some detail on the empirical methodology. Empirical results are then presented, while implications and directions for further research are discussed in the final section.

[2]In Figure 1, we indicate the hypothesized signs of the relationships between variables that will be discussed later in § 4. We will also confirm in § 6 that these signs are observed in our empirical analysis of the personal computer industry.

Figure 1 Approaches To Studying the Impact of Product Proliferation



2. Prior Literature

Generally speaking, the existing literature concentrates on *either* the determinants *or* the consequences of a proliferation strategy. For example, Connor (1981) relates several market structure variables to counts of the number of new products introduced into over one hundred food categories during 1977–1978. 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 product models it has produced in the past, the more likely it is to spread its products in the quality spectrum. However, despite the importance of firm product line decisions and related proliferation strategies, we are unaware of any other empirical research that examines factors related to a firm's product line decision.

A handful of studies address the market outcomes associated with product proliferation. Among the results of their advertising study for example, Roberts and Samuelson (1988) find that a firm's market share in the low-tar cigarette industry is positively related to the number of its own brands (and negatively related to the number of its competitor's brands). Cook and Rothberg (1990) report a significant Spearman rank correlation between market share and share of product models for the twelve domestic automobile competitors between 1973–1981. Kekre and Srinivasan (1990) analyze subjective managerial assessments of relative product line breadth (via a three-point ordered scale) by pooling times series and cross-sectional PIMS data across numerous diverse consumer and industrial industries. Their results suggest that business units with broader product lines have larger market shares and higher profitability, but also higher prices. Robinson and Fornell (1985) and Robinson (1988) report similar findings using PIMS data. Putsis (1997) examines the number of brands sold in each of 59 geographic markets and over two hundred categories using annual IRI market-level data on food products. He finds that an increase in the number of brands increases the ability of national brand manufacturers to raise price (see also Levy and Reitzes 1993), but that this relationship depends upon the dispersion of sales across existing brands. Kadiyali et al. (1998) assess the impact of a single line extension in the yogurt category using the new empirical industrial organization framework. They conclude that broadening a product line through a line extension increases the market power of the extending brand, and helps to increase the sales and margins of both the extending and rival firms.

This brief literature review clearly indicates a need for more empirical studies of product proliferation and related market performance effects. Consistent with the objectives of our research, we identify three important aspects of the existing literature in need of further investigation. First, we are unable to find any empirical effort that econometrically relates *objective* measures of product proliferation (e.g., product line length) to market outcomes (e.g., market share and price). Second, prior research has not recognized the endogeneity of the product line decision. Finally, no study has considered a unified framework to empirically estimate the determinants and consequences of a firm's product line decisions, i.e., no study simultaneously considers the demand, supply, and broader strategic considerations associated with a product proliferation strategy. We address all three in our empirical analysis in this paper.

3. The Personal Computer Industry

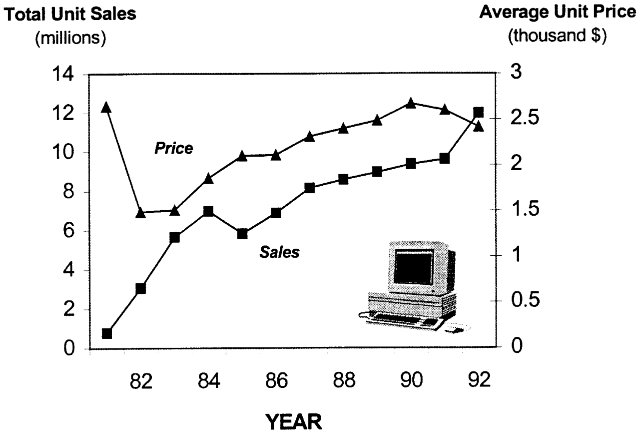
In this section, we provide a general overview of the empirical setting. This background information on the personal computer industry will furnish a specific context in which to better understand the nature of individual firm decisions and will guide the model development in § 4.

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) is used. As noted by Lawless and Anderson (1996), IDC is the oldest among the various firms that tracks the American computer industry and is widely respected. IDC began its PIC in 1964, and is recognized as having a very accurate picture of the activity in this industry. Annual firm-level data for the personal computer industry were constructed from the detailed product-level information in the IDC database.

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 12 years are characterized by rapid expansion in sales (e.g., see Bayus 1998). Figure 2 shows the growth in unit sales, as well as the average annual price[3] per unit. During this period, sales grew from under 800,000 units to almost 12 million units in 1992. Technology

[3]Nominal prices are reported in Figure 2 and are used in our estimations. There is some ambiguity in the economics literature on the role that real versus nominal prices play in firm decisions (e.g., see the review book by Sheshinksi and Weiss 1993, and especially Weiss' introductory chapter). Consequently, we also adjusted nominal prices using the annual technology sector CPI deflator (US Bureau of Labor Statistics, 1980 = 100). Using real prices produced almost *identical* results and conclusions.

Figure 2 Total Personal Computer Unit Sales and Average Unit Prices



also improved substantially over this period. For example, the microprocessors[4] used in the first generation personal computers (e.g., Intel's 8080 and Zilog's Z80) were superceded by second generation (e.g., Intel's 80286 introduced in 1982), third generation (e.g., Intel's 80386 introduced in 1985), and fourth generation (e.g., Intel's 80486 introduced in 1989) technology. Personal computers from each of these technology generations were in the market contemporaneously throughout the 12-year period. We also note that competition in this industry is very fragmented, e.g., in every year during this period there were over 100 competing manufacturers.

During this period, product proliferation is also very evident. As shown in Figure 3, the number of product models[5] available in the market steadily increased throughout this period so that by 1992 there were over 2,000 different product models offered for sale. In addition, the average length of product lines expanded rapidly from around two products in 1986 to over seven product models in 1992, while the number of firms competing in the industry increased dramatically over this period (see Figure 3). We note that 1986 corresponds to the peak sales of personal computers based on Intel's 8088 microprocessor (e.g., the IBM PC), and sales of personal computers based on more advanced technology (e.g., Intel's 80286 and 80386 CPUs) rose quickly thereafter (e.g., see Bayus 1998).

In summary, the personal computer industry over this 12-year period is an excellent setting in which to examine the effects of product proliferation. Many, but not all, firms were active in expanding their product lines. More important, detailed data on firms' product line decisions are available for a large set of competitors over several years. Thus, we can construct measures of market share (*SHARE* is defined to be the ratio of a firm's total sales across its entire product line to total industry sales), price (*PRICE* is defined to be the average price across a firm's product line, weighted by sales),[6] and product proliferation (*PLINE* is defined to be the number of product models offered for sale by a firm), as well as several other firm-level and market-level variables to capture strategic considerations. Variable definitions along with descriptive statistics are in Table 1.

[4]As discussed in Lawless and Anderson (1996), 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. Thus, CPU design determines the computer's overall power and performance.

[5]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).

[6]We consider average price weighted by sales rather than other measures of price (e.g., the highest price of any product in a firm's line) for several reasons. First, related research in the personal computer industry finds that firms actually expand their product lines with products based on newer *as well as older* technologies (Bayus 1998). In general, it follows that a firm will not base its product line decisions *only* on the highest prices it may be able to obtain for new products (e.g., for the new technology product), but also upon the prices it may obtain for older technology products as well. Second, new product introduction decisions are likely to depend upon the distribution of sales across the set of new products introduced. Thus, our use of a weighted average price (*PRICE*) in this context seems like a reasonable way to balance across these various effects.

Figure 3 Product Proliferation and the Number of Firms in the Personal Computer Industry

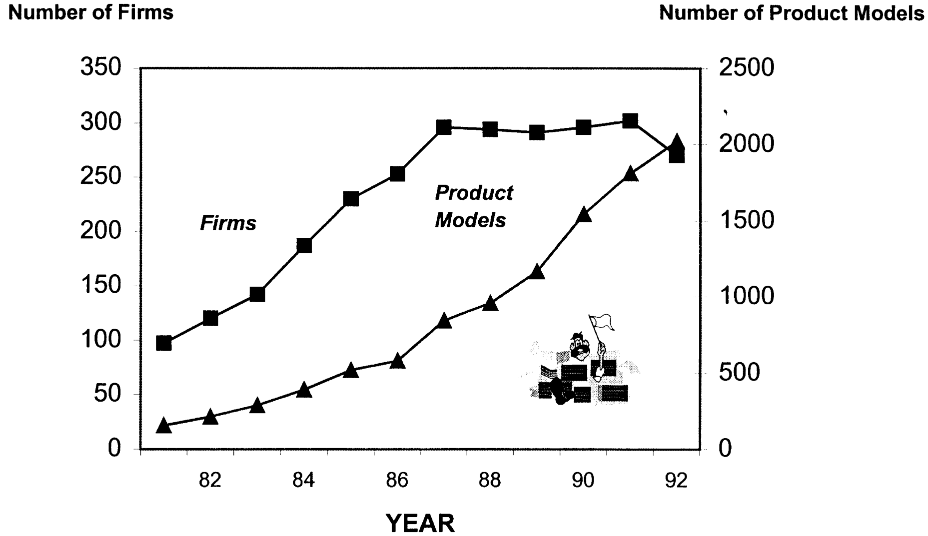


Table 1 Variables and Descriptive Statistics

Variable Name	Variable Definition	Mean	Standard Deviation
SHARE	Market share for firm in period *t*	0.0048	0.0216
PRICE	Average price ($000) across firm's product line in period *t*, weighted by sales	2.98	2.76
PLINE	Number of product models offered by firm in period *t*	3.96	5.14
CPRICE	Average price ($000) across competitor's product line in period *t*, weighted by sales	2.30	0.33
CPRODUCTS	Total number of competing product models available in period *t*	1053.9	585.9
FIRMAGE	The firm's age (in years) in period *t*	3.16	3.29
HHI	Hirfindahl index of industry concentration in period *t*	0.0780	0.0421
FIRMTECH	The number of microprocessor technologies offered by firm in period *t*	1.81	0.89
CLINE	The average number of product models offered by all competitors in period *t*, weighted by sales	3.86	1.83
MGROWTH	Percentage growth rate, market-wide from period *t*-1 to *t*	2.19	14.64

4. Model Development and Hypotheses

In this section, we build on the prior literature by developing an integrative empirical framework that addresses both the determinants and consequences of product proliferation strategies. We begin by discussing the general intuition behind our empirical framework. Using the existing literature, we then develop the underlying theoretical framework for demand, supply, and product line length in more detail. We conclude this section with a summary of our central hypotheses and a discussion of how these will be tested.

Intuitively, a firm is likely to face the following dynamics. The firm's demand (share) depends upon the firm's price schedule and the length of its product line, as well as other factors such as competitor actions. A broader product line makes it more likely that at least one of the firm's products will match any individual consumer's preferences most closely. Thus, a lengthening of its product line should result in an increase in the overall demand for the firm's products. However, as its product line gets broader, a firm's costs are also likely to increase due to added complexity and loss of scale economies in the production process. Therefore, a broader product line leads to higher prices on the supply side. To decide on an optimal length for its product line, the firm must balance the positive demand effects of a broader line with the negative effects on production costs. The firm's product line decision will also be influenced by external strategic factors such as competitor actions (e.g., entry deterrence). These dynamics suggest that a firm considers demand (market share), supply (price), and its product proliferation strategy simultaneously.[7]

4.1. Demand

Early models addressing product variety were primarily concerned with explaining the *existence* of variety in the market, rather than in understanding the strategic proliferation decisions of individual firms. Models of monopolistic competition initially evolved from research that considered firms selling a single product (Chamberlin 1933). In such a framework, firms do not proliferate since each firm sells only one product by assumption. The Chamberlinian market, however, does observe product variety. Markets characterized by the absence of scale economies in production and/or a small elasticity of substitution between goods in the market can sustain a higher number of firms in equilibrium, and hence will have a larger number of products (equal to the number of firms; Lancaster 1990). Note that while this is merely an artifact of the assumptions of these early models, it does highlight the importance of a firm-level analysis—we can observe market-wide "proliferation" (i.e., variety) even when no individual firm engages in a proliferation strategy. Thus, it is important to differentiate between product variety per se and the proliferation strategies of individual firms.

While also restricting their analysis to single-product firms, neo-Chamberlinian models (e.g., Hart 1985a, 1985b; Perloff and Salop 1985) assume that each individual consumer has a vector of relative values for product offerings in a category. Given prices, the consumer chooses the product that generates the greatest surplus (i.e., value minus price). To formulate our hypothesis about the influence of firm proliferation decisions on the demand faced by a firm, we combine this intuition with previous applications of economic models of product variety to consumer preference distributions (e.g., Hauser and Shugan 1983, Hauser and Gaskin 1984).

Consistent with the existing literature (e.g., Connor 1981, Stavins 1995), we use a spatial analogy in thinking about the demand effects of product proliferation. Thus, the personal computer market can be thought of as consisting of several dimensions; each dimension defines a product-attribute space that may have some unfilled market segments (e.g., see Stavins 1995). A proliferation strategy, then, is the firm's attempt to fill these empty spaces. Given heterogeneity in consumer preferences, a broader product line implies a higher probability that at least one of the firm's product offerings will most closely match an individual consumer's preferences. For example, for each of the preference distributions discussed in Hauser and Gaskin (1984, Figure 4), any reasonable new product introduction will attract a positive number of consumers. As a result, aggregate demand for firms with long product lines should be relatively high. We also expect that there are decreasing returns to product line length for two reasons (e.g., see Schmalensee 1978, Brander and Eaton 1984): (1) the more disperse the firm's product line is in attribute space, the more difficult it is to find an incrementally profitable unoccupied location in this space, and (2) cannibalization becomes increasingly difficult to avoid with longer product lines. Thus, we hypothesize that product proliferation increases demand at a decreasing rate. In addition, to be consistent with economic theory demand should be downward sloping in price.

We also consider several other exogenous demand-shift variables that have been used in previous studies (Table 1, presented earlier, contains descriptive statistics for all variables): *CPRICE* (the average price across all *competing* product lines, weighted by sales), *CPRODUCTS* (the total number of competing product

[7]We note that one possible approach to formalizing this discussion would be to take a new empirical IO approach to this problem. For example, we could specify, *a priori,* the form of the competitive interaction between market players (e.g., Gasmi et al., 1992) or use a conjectural variations approach (e.g., Kadiyali et al. 1998). The structural equations to be estimated could then be derived using appropriate cross-equation restrictions. However, given the large number of competing firms in the personal computer industry, as well as the fragmented competitive and dynamic structure of this industry, such an approach would be exceedingly difficult, if not impossible, to apply in our study.

models), and *FIRMAGE* (the firm's age in years). To be consistent with economic theory, we expect that the relationship between demand (*SHARE*) and *CPRICE* is positive (competitor products are substitutes), while the relationship between *SHARE* and *CPRODUCTS* is expected to be negative (the larger the number of available substitutes, the lower the demand for the firm's product). Additionally, we expect that the relationship between *SHARE* and *FIRMAGE* is positive for several reasons. First, early entrants tend to have a market share advantage over later entrants (e.g., Robinson and Fornell 1985, Robinson 1988). Older firms also often enjoy reputation advantages in dynamic technological environments (e.g., Womack et al. 1990). The survival hypothesis (e.g., see Scherer 1980) also suggests that firms that have been in the market longer survive precisely because they have distinct market advantages (e.g., superior managers who are more adept at product positioning).

4.2. Supply

With respect to supply, a key component in our model development concerns the costs a firm may incur by engaging in a product proliferation strategy. Previous research has discussed the production efficiencies related to standardization and the loss of scale economies that may result from producing an increased number of products (e.g., Baumol et al. 1982, Quelch and Kenny 1994, Putsis 1997). Further, the added complexity of design and production, and added inventory costs, are likely to increase as well.[8] As a result, we hypothesize that there are positive and increasing costs associated with longer product lines. This in turn implies that price must increase at an increasing rate as a firm lengthens its product line to compensate for the added costs due to production complexity in this competitive environment. Thus, we hypothesize that product proliferation increases costs at an increasing rate. This in turn results in a positive and increasing (inverse) supply curve in product line length.

Conversely, in the presence of scale economies, a higher share should be associated with lower costs (e.g., Ravenscraft 1980, Beattie and Taylor 1985). Further, it has been argued that firms that are able to obtain higher share in very competitive industries (such as the personal computer industry) are often able to do so precisely because of production efficiencies and a lower cost structure (e.g., Demsetz 1973, Scherer 1980, Kekre and Srinivasan 1990). Thus, we also hypothesize that high market share is associated with production efficiencies and, thus, lower prices.[9]

We also note that the entry deterrence argument (e.g., Schmalensee 1978, Brander and Eaton 1984) can be tested by examining the estimated relationship between *PRICE* and *CPRODUCTS.* The rationale is that the larger and more disperse the marketwide number of product models, the more difficult it is for a potential entrant to find a desirable market position. This enables incumbents to raise price. Thus, if entry deterrence holds in this industry, we expect that there is a positive supply-side relationship between *PRICE* and *CPRODUCTS.* Note that this formulation allows us to separate out the entry deterrence argument from a cost-based argument since entry deterrence depends on the number of products offered *marketwide,* whereas cost-based arguments are firm specific (and hence rely on measures of a *firm's* product line length). Furthermore, due to the simultaneous estimation of *SHARE, PRICE,* and *PLINE,* this coefficient provides a convenient test of this hypothesis, holding the other effects of proliferation constant (unlike previous tests of the Schmalensee hypothesis).

We also consider several other independent variables that have been used in previous studies (as before, Table 1 contains descriptive statistics). These variables include *CPRICE, HHI* (the Herfindahl Index),[10]

[8]We note that the cost implications of specialized production have changed somewhat in more recent years. Inventory holding costs in particular have been reduced or eliminated by production processes that occur on an order-by-order basis (e.g., with Dell Computer, and more recently with Compaq).

[9]We note that an alternative argument can be made that increased share is associated with higher market power and thus, higher prices (e.g., Scherer 1980, Weiss 1989). However, such arguments are rarely made in highly competitive industries where even the market leaders have small market shares. We recognize that this may not be true for all industries.

[10]We note that the Herfindahl Index is specified as endogenous in our estimations, following the methodology suggested by Nevo (1998). Specifically, an instrument is created by forming a weighted average of previous period indices (the weights created by time series regressions). This created an instrument correlated with the current period Herfindahl at over 90%, but that is predetermined in the current period.

and *FIRMTECH* (the number of microprocessor technology generations offered). We expect that the price reactions will be positive since price increases and decreases are likely to be approximately matched by rival firms in competitive industries (e.g., Leeflang and Wittink 1992, Cotterill et al. 1998). Thus, the supply-side relationship between *PRICE* and *CPRICE* is expected to be positive. Furthermore, since there is a wealth of evidence linking high levels of industry concentration to higher prices (e.g., Ravenscraft 1980, Weiss 1989), we expect *PRICE* and *HHI* to be positively related. Following the arguments set forth by Ravenscraft (1980), *HHI* captures the traditional effects of industrywide coordinated behavior and market power in the industry we study, whereas market share captures firm specific cost-related effects. Finally, due to the dynamic nature of technology in the personal computer industry, we include a variable that captures the breadth of technology platforms a firm has in its product line (*FIRMTECH*). Based on previous work in this industry setting (e.g., Lawless and Anderson 1996), we expect that the relationship between *PRICE* and *FIRMTECH* is negative since firms with older personal computer technologies (and thus higher values of *FIRMTECH*) tend to have lower prices.

4.3. Product Line Length

In developing our hypotheses in the previous two sections, we rely on previous research addressing the underlying economics driving firm demand and related supply decisions. We now build on this research by applying it to the firm's product line length decision. Given heterogeneity in consumer preferences, we expect that firms with high market share will also tend to have a more heterogeneous customer base. To appeal to this diverse customer base, these firms need a broader product line (e.g., see Schmalensee 1978, Brander and Eaton 1984, Stavins 1995). As a result, we hypothesize that higher market share encourages broader product lines. In addition, the greater the ability of a firm to price above marginal costs, the larger is the expected return to new product introductions. Thus, any firm that can command a price premium for its products also has a greater incentive to introduce new products. Therefore, ceteris paribus, higher prices are expected to encourage firms to broaden their product lines (e.g., see Easterfield 1964, Murray and Wolfe 1970, Shapiro 1977). Thus, we hypothesize that higher prices encourage broader product lines.

We also consider several other independent variables that have been used in previous studies (see Table 1 for descriptive statistics). These variables include *FIRMTECH*, *MGROWTH* (the percentage growth rate in total industry sales), and *CLINE* (the average number of product models offered for sales across all competitors, weighted by sales). Based on previous work in this industry setting (e.g., Stavins 1995, Lawless and Anderson 1996, Bayus 1998), firms tend to fill out their offerings within each technology generation in their product line to reduce potential competitive threats. Thus, we expect that the relationship between *PLINE* and *FIRMTECH* is positive. We also expect that the relationship between *PLINE* and *MGROWTH* is positive since a high market growth rate implies a greater incentive for all firms to increase the length of their product line to satisfy the various growing consumer segments (e.g., Lancaster 1979, 1990; Quelch and Kenny 1994). Finally, the longer the rival's product line length, the greater the competitive pressure to offer a broader product line (e.g., Lancaster 1990). Thus, we expect that *PLINE* and *CLINE* are positively related.

4.4. Summary of Key Hypotheses

The discussion so far highlights the role of previous research in developing a foundation for understanding the impact of proliferation. From this discussion, we are able to form seven central hypotheses that relate to the impact and determinants of strategic proliferation decisions. These hypotheses are summarized in Table 2 (columns 1, 2). As noted in this table, some hypotheses have very strong theoretical and empirical support, while others are more speculative due in large part to a limited existing literature on product line determinants (see Table 2, column 4). Table 2 (column 3) also presents an appropriate test for each hypothesis.

5. The Econometric Model and Estimation Issues

Consistent with prior research (e.g., Kekre and Srinivasan 1990; Lawless and Anderson, 1996), we study 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

Table 2 **Summary of Central Hypotheses**

Hypothesis	Equation	Hypothesis Test	Prior Support	Hypothesis Test Results for the PC Industry	Conclusion
1. *Product proliferation increases demand, at a decreasing rate.*	Demand (Share)	$\frac{\partial SHARE}{\partial PLINE} > 0$ *and* $\frac{\partial^2 SHARE}{\partial^2 PLINE} < 0$	Strong theoretical support, with some empirical support.	$\frac{\partial SHARE}{\partial PLINE} = 0.99 > 0$ but $\frac{\partial^2 SHARE}{\partial^2 PLINE}$ not significantly different from 0	Partially Supported
2. *Demand is downward sloping in price.*	Demand (Share)	$\frac{\partial SHARE}{\partial PRICE} < 0$	Very strong theoretical and empirical support.	$\frac{\partial SHARE}{\partial PRICE} = -2.07 < 0$	Supported
3. *Product proliferation increases costs at an increasing rate, that in turn, results in positive and increasing prices in product line length.*	Supply (Price)	$\frac{\partial PRICE}{\partial PLINE} > 0$ *and* $\frac{\partial^2 PRICE}{\partial^2 PLINE} > 0$	Strong theoretical support, with some empirical support.	$\frac{\partial PRICE}{\partial PLINE} = 1.54 > 1$ which is consistent with $\frac{\partial PRICE}{\partial PLINE} > 0$ *and* $\frac{\partial^2 PRICE}{\partial^2 PLINE} > 0$	Supported
4. *High market share is associated with cost efficiencies and thus, lower prices.*	Supply (Price)	$\frac{\partial PRICE}{\partial SHARE} < 0$	Very strong theoretical and empirical support in highly competitive industries.	$\frac{\partial PRICE}{\partial SHARE} = -0.29 < 0$	Supported
5. *Product proliferation deters competitive entry.*	Supply (Price)	$\frac{\partial PRICE}{\partial CPRODUCTS} > 0$	Strong theoretical support, with some empirical support.	$\frac{\partial PRICE}{\partial CPRODUCTS}$ not significantly different from 0	Not Supported
6. *Higher market share encourages longer product lines.*	Product Line Length	$\frac{\partial PLINE}{\partial SHARE} > 0$	Some theoretical support, but no prior empirical support.	$\frac{\partial PLINE}{\partial SHARE} = 0.15 > 0$	Supported
7. *Higher prices encourage longer product lines.*	Product Line Length	$\frac{\partial PLINE}{\partial PRICE} > 0$	Some theoretical support, but no prior empirical support.	$\frac{\partial PLINE}{\partial PRICE} = 0.87 > 0$	Supported

firm, while the cross-sectional nature of the data allows us to also exploit interfirm variability in product line decisions. In contrast to the published research (e.g., Kekre and Srinivasan 1990, Putsis 1997), the discussion in the previous section suggests that any estimation procedure should recognize that share, price, and product line length are jointly endogenous.[11] As a result, we employ three stage least squares (3SLS) to estimate the three-equation system, allowing for cross-equation error correlations in estimation. Given the time series component of the data, we also address the possibility of serially correlated errors below.

Although previous research generally has employed a linear functional form for share and price (e.g., Kekre and Srinivasan 1990), a nonlinear form is particularly relevant in our context since we hypothesize decreasing returns to product line length on the demand side, and costs increasing at an increasing rate (as the firm's product line increases) on the supply side. We thus considered two functional forms for the demand and supply specifications and used nonnested hypothesis tests to decide upon the final functional form. We compared a logarithmic specification of the demand and supply equations to a linear form using a nonnested P-E test (Davidson and MacKinnon 1981). Balasubramanian and Jain (1994) suggest that the choice of a nonnested test should be guided by the circumstances surrounding the test (e.g., see their Table 7 for the appropriateness of the P-E test in our situation). We employ this test as detailed in Greene (1997). The results for all three equations were conclusive: the P-E test strongly rejected the null of a linear demand and supply model at $p < 0.0001$.[12]

Given our discussion to this point, we specify the following equations to study the product line determinants and market outcomes in the personal computer industry (where ω_1, ω_2, ω_3 denote equation errors, assumed to be contemporaneously correlated across equations):

$$\text{SHARE} = \alpha_1\ \text{PRICE}^{\theta_1}\ \text{PLINE}^{\theta_2}\ \text{FIRMAGE}^{\theta_3}\ \text{CPRICE}^{\theta_4}\ \text{CPRODUCTS}^{\theta_5}\ e^{\omega_1}, \quad (1)$$

$$\text{PRICE} = \alpha_2\ \text{SHARE}^{\eta_1}\ \text{PLINE}^{\eta_2}\ \text{FIRMTECH}^{\eta_3}\ \text{CPRICE}^{\eta_4}\ \text{CPRODUCTS}^{\eta_5}\ \text{HHI}^{\eta_6}\ e^{\omega_2}, \quad (2)$$

$$\text{PLINE} = \alpha_3\ \text{SHARE}^{\phi_1}\ \text{PRICE}^{\phi_2}\ \text{FIRMTECH}^{\phi_3}\ \text{CLINE}^{\phi_4}\ \text{MGROWTH}^{\eta_5}\ e^{\omega_3}. \quad (3)$$

Since the data vary across time, at a minimum, fixed effects capturing differences across the years of estimation should be incorporated into the empirical analysis. Furthermore, heterogeneity across firms suggests that a random effects model may be more appropriate (e.g., see Judge et al. 1985, Green 1997). We statistically tested the need for fixed effects in estimation using a Likelihood Ratio (LR) test (essentially testing the model with and without individual year binaries under the null of no fixed effects). We then compared a fixed effects and a random effects model using a Hausman (1978) test (see Greene 1997 for a discussion). The LR test strongly supported the inclusion of fixed effects for all three equations at $p < 0.01$, while the Hausman test rejected the need for random effects at $p < 0.01$.[13]

Given the time-series nature of data used, serially correlated errors are also a concern. If this is the case, then the use of weighted three stage least squares (W3SLS) or alternative procedures would be appropriate (see Greene 1997, pp. 662–669). For the personal computer data, we examined the residuals produced under 3SLS with fixed effects using both the Breusch-Godfrey statistic and the Box-Pierce Q statistic (see Greene 1997, pp. 594–596 for a discussion and comparison of the two test statistics) for AR(1) and AR(2) residuals (note that if we reject AR(1) and AR(2), higher order error processes are unlikely). We could not reject the null hypothesis of no serial correlation at $p = 0.10$ or better for either the AR(1) or AR(2) error processes. Thus, the residuals under 3SLS and fixed

[11]It is well known that OLS applied equation by equation to jointly endogenous variables will produce inconsistent parameter estimates (e.g., see Judge et al. 1985) and can result in improper signs on key variables (e.g., see Cotterill et al. 1998). Simultaneous equation approaches to estimation have a long history in marketing (e.g., Hanssens et al. 1990).

[12]We conducted this test both with and without fixed effects, with similar results.

[13]The Hausman test was employed as detailed in Greene (1997, pp. 632–634). Rejection of the null implies that the random effects estimator is inconsistent. The use of the Hausman test, the LR test and the properties of W3SLS are well known, and accordingly are not discussed here. See Greene (1997) for additional details.

effects demonstrated no significant error correlations for each of the three equations. Consequently, 3SLS with fixed effects as opposed to W3SLS is used in the empirical analysis reported in the next section. Therefore, we assume that the equation errors are correlated across equations, but are independent across time periods.

Finally, we note that the three competitor variables *CPRICE, CPRODUCTS,* and *CLINE* are exogenous in our estimations. We take this approach since the large number of firms in this market (see Figure 3) suggest that these variables are unlikely to be affected by the action of any single firm.[14]

6. Empirical Results

The 3SLS estimation results with fixed effects[15] for our three-equation system consisting of Equations (1), (2), and (3) is in Table 3. Since traditional R^2 measures are not bounded between zero and one in 3SLS, Carter and Nagar's (1977) multiple squared coefficient of correlation for simultaneous systems, R_w^2, is used instead. The estimated system fits the personal computer data well, with the system-wide R_w^2 equal to 0.421.[16] All of the significant coefficients have the expected signs.

We note that the estimated price elasticities are consistent with previous empirical research. In the demand equation, the estimated own-price elasticity of −2.07 is within the range reported in Tellis' (1988) meta-analysis, while the cross-price elasticity of 0.96 is less than the (absolute value) own-price elasticity as expected. The price reaction estimate of 1.17 in the (inverse) supply equation is consistent with other empirical results (e.g., Cotterill et al. 1998) and suggests that industry-wide price cuts are essentially matched.

Our central hypotheses and their tests are summarized in Table 2 (columns 5, 6). Five of our hypotheses are strongly supported, and one hypothesis is partially supported. While we do observe positive returns to line length on the demand side, since the estimated coefficient of *PLINE* in the *SHARE* equation is not significantly different from one, we do not observe decreasing (demand) returns to product line length (the estimated returns exhibit constant returns to scale). Thus, these results confirm the directional relationships we noted in Figure 1b. Finally, as shown in Table 2 (column 6), these data do not support Schmalensee's (1978) argument that product proliferation deters entry in the personal computer industry.

All of the exogenous variables representing strategic considerations are statistically significant and are of

Table 3 Estimation Results

Demand Equation, Dependent Variable: *SHARE*

Variable	Coefficient	Standard Error	$z = b/s.e.$	$P[Z > z]$
PRICE	−2.0666	0.23936	−8.634	0.00000
CPRICE	0.96154	0.47813	2.011	0.04432
PLINE	0.99220	0.15243	6.509	0.00000
CPRODUCTS	−1.4073	0.67703E-01	−20.786	0.00000
FIRMAGE	1.0665	0.10634	10.029	0.00000

Price (Inverse Supply) Equation, Dependent Variable: *PRICE*

Variable	Coefficient	Standard Error	$z = b/s.e.$	$P[Z > z]$
SHARE	−0.29124	0.56597E-01	−5.146	0.00000
CPRICE	1.1734	0.44799	2.619	0.00882
PLINE	1.5401	0.22389	6.879	0.00000
CPRODUCTS	0.45181E-01	0.20245	0.223	0.82340
HHI	1.1021	0.26649	4.136	0.00004
FIRMTECH	−1.5568	0.17384	−8.956	0.00000

Product Line Length Equation, Dependent Variable: *PLINE*

Variable	Coefficient	Standard Error	$z = b/s.e.$	$P[Z > z]$
PRICE	0.87440	0.66485E-01	13.152	0.00000
SHARE	0.15125	0.14114E-01	10.716	0.00000
FIRMTECH	1.1459	0.48618E-01	23.570	0.00000
MGROWTH	0.15726E-01	0.56469E-02	2.785	0.00535
CLINE	0.67993	0.59659E-01	11.397	0.00000

Estimation: 3SLS with Fixed Effects.
System $R_w^2 = 0.421$.
Number of Observations: 1720.
Note. All variables expressed in LN form, consistent with Equations (1), (2), and (3).

[14]This assertion is confirmed by a Hausman (1978) test. When we instrument for these variables in 3SLS, we find that while both estimators are consistent, the IV estimator is inefficient.

[15]The results for the fixed effects (i.e., binary year variables) are not reported here in the interest of brevity.

[16]R_w^2 measures the percent of system-wide variation explained by all the independent variables in the system, and is bounded between zero and one. However, we note that this statistic is frequently very high and should be interpreted with caution (e.g., see Berndt 1991).

the expected sign. In particular, the results in Table 3 show the importance of competitive factors. As expected, the effect of competitive price is positive in the demand and supply equations. In addition, competitive crowding in the product space limits the market share a firm can achieve (i.e., *CPRODUCTS* is negatively related to *SHARE*). Consistent with previous research (Weiss 1989), *HHI* also positively affects price, suggesting that a more concentrated industry environment is associated with less price competition (and thus higher prices). Finally, broader competitive product lines are positively related to increased proliferation by a firm.

On the demand side, the results in Table 3 indicate that a proliferation strategy is related to an increase in the overall demand faced by a firm. We note that this result is consistent with the prior empirical literature (e.g., Robinson and Fornell 1985, Robinson 1988, Roberts and Samuelson 1988, Kekre and Srinivasan 1990, Kadiyali et al. 1998). In line with other research involving the personal computer industry (e.g., Stavins 1995; Bayus 1998), we also find that older firms tend to have a share advantage over newer entrants. On the supply side, our results are in agreement with Putsis (1997) since they imply that a broader product line is associated with higher prices and thus, higher costs. In contrast to these prior studies however, the results in Table 3 demonstrate that the impact of proliferation strategies in the personal computer industry does not have a single explanation. Instead, as suggested by Lancaster (1990) and Ratchford (1990) the market outcomes associated with product proliferation have *both* demand *and* cost implications.

To illustrate this last point, note that despite the *positive* coefficient of *PLINE* in the demand equation, the results suggest that the *net* market share impact of product proliferation in the personal computer industry over the period 1981–1992 is *negative.*[17] This implies that the cost increases associated with proliferation strategies in this industry dominate the potential demand increases. We note that firms in the personal computer industry have recently recognized the increased cost and complexity implications linked to their product lines and have taken actions to cut costs by reducing the length of their lines and altering the manufacturing process (e.g., Carlton 1993, Hays 1994, Narisetti 1998). This is also consistent with a broader trend among manufacturers in other industries (e.g., Quelch and Kenny 1994, Narisetti 1997).

With respect to product line determinants, the results in Table 3 indicate the importance of endogenous (*SHARE* and *PRICE*) and related exogenous factors. If industry sales are growing or if competitors broaden their product line, there is a general incentive for firms in the personal computer industry to engage in a product proliferation strategy. In addition, the positive coefficient for *FIRMTECH* in the *PLINE* equation suggests that firms tend to introduce new product models at a faster rate than they withdraw older products. This finding is also consistent with other research involving the personal computer industry (e.g., see Stavins 1995, Bayus 1998).

To emphasize the importance of our estimation approach, we also estimated a two-equation system of just share and price (omitting Equation (3)) using 3SLS with fixed effects (in essence mimicking part of the system estimated by Kekre and Srinivasan 1990). Although Kekre and Srinivasan (1990) used a different model formulation applied to a different data set (with an admittedly different purpose), we are able to replicate some of their key findings using this two-equation system. For example, Kekre and Srinivasan (1990) unexpectedly find that production costs *fall* as product lines become broader. In addition, they find that product line length is positively related to share which, in turn, is positively related to ROI (and thus is consistent with the Schmalensee (1978) entry deterrence argument). Although the details are not reported here, Equations (1) and (2) applied to the personal computer data (without allowing for the endogeneity of product line length) give similar results to those obtained by Kekre and Srinivasan (*PLINE* is *negatively* related to *PRICE*, consistent with Kekre and Srinivasan's unexpected result that broader product lines are associated with lower costs, and *CPRODUCTS* is *positively* related to *PRICE*, which is consistent with the entry deterrence hypothesis). Comparing these results to those in Tables 2 and 3, we note that the estimated impact of *PLINE* on *PRICE* is reversed

[17]This can be seen by substituting the *PRICE* equation into the *SHARE* equation and combining the coefficients for *PLINE*. From Table 3, the exponent for *PLINE* is $(-2.07)(1.54) + (0.99) = -2.20$.

once the product line length decision is specified as endogenous. In addition, support for the entry deterrence argument disappears when endogeneity and simultaneity are addressed in estimation.[18]

To summarize, we return to Figure 1. Our results suggest that understanding the impact of a proliferation strategy is more "complex" than the results reported by previous research. Furthermore, our findings reported in Tables 2 and 3 provide empirical evidence that the intuition outlined in § 4 is consistent with the personal computer industry over the years studied. Specifically, we see that while there is a strong positive incentive to engage in a product proliferation strategy (i.e., (i) broader product lines lead to higher demand, which in turn encourages even broader product lines, and (ii) broader product lines are associated with higher costs and thus higher prices, which in turn encourage even broader product lines), there is also a balancing downward pressure on firms to shorten their product lines (i.e., (i) higher prices which result from the increased costs associated with broader product lines lead to lower demand, and thus lessen desire to lengthen the product line, and (ii) the higher share that results from broader product lines is also associated with lower prices, and thus a reduced incentive to continue expanding the product line). We suggest that these results, obtained from the estimation of this three-equation system, paint a more "complete" picture of proliferation than previous research.

7. Conclusions

In response to the lack of any research that simultaneously considers the demand, supply, and strategic considerations of product proliferation, we have proposed a three-equation simultaneous system that captures both the determinants and market outcomes of a firm's product line decisions. Our proposed model considers market share, price, and product line length to be jointly endogenous. Using this structure, we empirically study the market share and price effects of product proliferation in the personal computer industry over the period 1981–1992. Our empirical results demonstrate that product proliferation has both demand (market share) and cost (price) implications. In addition, we find no support in the personal computer industry for the argument that product proliferation raises prices via entry deterrence. However, our empirical results do suggest that competitive factors play an important role in the determinants and market outcomes of a firm's product line decisions. Further, this estimation approach allows us to offer a possible explanation for some of the empirical results previously reported in the literature (e.g., the statistical estimates of Kekre and Srinivasan 1990 indicating that manufacturing costs are *lower* for broader product lines).

Keeping in mind that our ability to generalize beyond the data we analyze is somewhat limited, several implications should be noted. In the personal computer industry, the higher market share and higher prices associated with product proliferation have both demand *and* cost implications (see Table 3). Our empirical results indicate that the costs of product proliferation dominate any demand increases (i.e., the net market share impact of product proliferation is negative). In addition, our results suggest that firms with only products that have newer technology tend to have higher prices but smaller market shares.[19] We note, however, that many of these conclusions are reversed when product line length is not considered to be jointly endogenous with market share and price.

Our results also suggest that product proliferation can be a doubled-edged strategy. A firm with a long product line may be able to obtain a high market share, but it can also end up with higher prices (due to the higher costs of the broad product line). These higher prices, in turn, put downward pressure on market share. In addition, firms have an incentive to engage in a proliferation strategy as the market grows. Thus, a market situation with an increasing amount of product variety and new product introductions, combined

[18]We note that Kekre and Srinivasan (1990, p. 1227), in explaining their unexpected results, suggest that firms may choose a number of strategies to mitigate any possible adverse impact of proliferation on cost (e.g., for example, downstream product differentiation). In the absence of cost data, we cannot say that a similar "reversal" would have occurred using their data. Our results do suggest that specifying the firm's product line length decision as an endogenous choice variable can have a powerful impact on the empirical results.

[19]This can be seen by substituting the *PRICE* equation into the *SHARE* equation and combining the coefficients for *FIRMTECH*. From Table 3, the exponent for *FIRMTECH* is positive.

with increasing product line costs, can arise. Interestingly enough, this is the condition that exists in the personal computer industry today (e.g., see Steffens 1994, Narisetti 1998). Possibly as a response to the market conditions suggested by our empirical results, 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 recently have 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.

It is also instructive to view our results in relation to other studies addressing the competitive effects of product line decisions. For example, Kadiyali et al. (1998) use a theoretically grounded empirical model (based upon a conjectural variations approach) to examine the impact of a line extension on price competition between two national manufacturers in the yogurt category. They find significant changes in the pattern of competitive interaction after a line extension is introduced. Our analysis suggests that the personal computer industry operates quite differently, although competitive dynamics play an equally important role. Due to the fragmented competitive environment in the personal computer industry, competition appears to operate at two levels. On one hand, firms need be concerned by the broader industry trends (e.g., overall number of products available to consumers). At the same time, firm specific factors (e.g., the diversity of product platforms offered by a firm) play an important role as well. Given the number of competitors in the personal computer industry, product entry and exit decisions are often driven by industry-wide influences rather than competitive interaction across duopolists (e.g., see Stavins 1995). Of course, this is also due in large part to the approach we take, but it also serves to highlight the potential benefits and insights to be gained from methodologies tailored to the industry being studied (e.g., the three-equation system used here for the personal computer industry and the NEIO framework employed by Kadiyali et al. (1998) for the yogurt market that is essentially a duopoly).

Given the excellent statistical fits for the personal computer data, our three-equation simultaneous system of equations seems to be a promising approach to empirically study the product line decisions of firms within such an environment. Thus, future research might attempt to generalize our results to other industry settings (e.g., including dynamic as well as stable product technologies). In this vein, we note that firm managerial skill can influence the relationship between product introduction and market share success (e.g., see Murthi et al. 1996). Consequently, future research should attempt to incorporate measures of managerial skill to ascertain how robust our results are in this regard. Finally, other explanatory variables can also be empirically explored. For example, product attributes may be used to examine changes in quality over time. Furthermore, we did not have any cost information available as part of our data set. With appropriate data (e.g., manufacturing costs, inventory costs, direct costs; see Kekre and Srinivasan 1990), future research could more directly examine the relationship between product proliferation and profitability.[20]

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