Firm Strategies in the Personal Computer Market: Are Established Brands Better Off?

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Since its beginnings in January 1975, the market for personal computers has ballooned. Yet the rising tide of demand has not lifted all boats, as New England and other entrants to the industry discovered. While some personal computer manufacturers managed to remain in the market for a number of years, many others left after a short time. This article examines some of the factors contributing to success in the personal computer industry, with particular attention to the role of experience.

Among the article's findings are that brand effects count for a lot. Models produced by firms with more experience, as measured by both years in business and numbers of models produced in the past, had greater longevity than similar models produced by less experienced companies. Another finding, one that runs somewhat counter to conventional wisdom, is that the more technically advanced models are introduced by the more experienced firms. This appears to be part of a dispersion strategy, by which established companies offer a variety of models, thereby avoiding replacing existing models and preempting top-of-the line market segments. New firms were more likely to concentrate their models in a particular market segment and to introduce models embodying established technologies.

The article analyzes patterns of entry and exit of individual models in the personal computer (PC) industry. In the case of entry, firms' decisions about which models to produce are analyzed, with a focus on asymmetries in location of new products[1] between incumbents and entrants. Who introduces the most technologically advanced models: entrants or incumbents? Do incumbents preempt the market by segmenting it, that is, do they locate all their models in a single market segment, or do they disperse their models along the product space? The advantage of incumbents over entrants is also tested in the case of exit. The questions addressed are whether firms' reputations and experience helped them

and their models survive in the market longer, controlling for models' prices and attributes.[2]

The article begins with a brief history of the PC industry in the United States, followed by an outline of some theoretical issues associated with strategic model location. Previous work in the area is then summarized. The next two sections describe the data used in this study and the way models' quality is measured. Then entry and exit results are provided. A summary and conclusions follow.

I. History

The microcomputer or personal computer industry in the United States has undergone major changes in its market structure. The industry has grown substantially from its beginnings in January 1975, when the first microcomputer, the Altair 8800, was introduced. During its early development, the industry was dominated by a few small-scale companies, mainly hobbyist-run. Entry into the market was determined by technological innovation and the availability of system-compatible software. Companies tended to design their own software, with little compatibility among systems. IBM introduced its personal computers in 1981 and dominated the market for several years. Gradually producers of software and hardware began separating, with less vertical integration and more compatibility among products.

The 1980s brought a large number of smaller firms into the market, making the industry more competitive. Figure 1 shows changes in the market concentration in the personal computer industry, as measured by the Herfindahl index,[3] while Figure 2 shows changes in total employment in the computer and office equipment industry. By the end of the 1980s, substantial product differentiation had occurred, with most firms offering several models, often with several versions each. Throughout the period, new product development was the engine of the industry's rapid growth. One Massachusetts-based computer manufacturer, Data General, claimed a new product or major product modification every 10 to 12 working days in 1980 (Kuhn 1982, p. 2).

In some high-tech industries, entry by new firms may be difficult because the existing companies incor-

Figure 1

The PC industry's market structure has become more competitive.

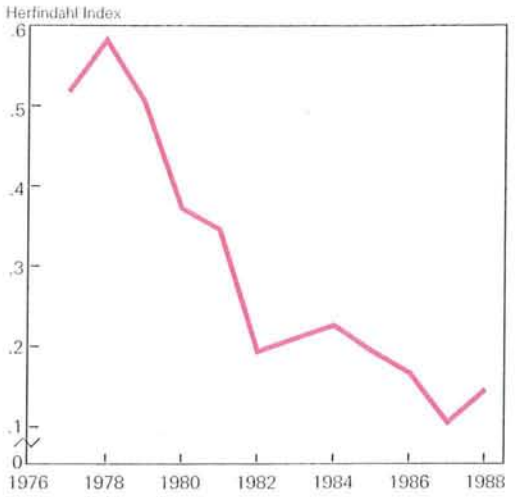
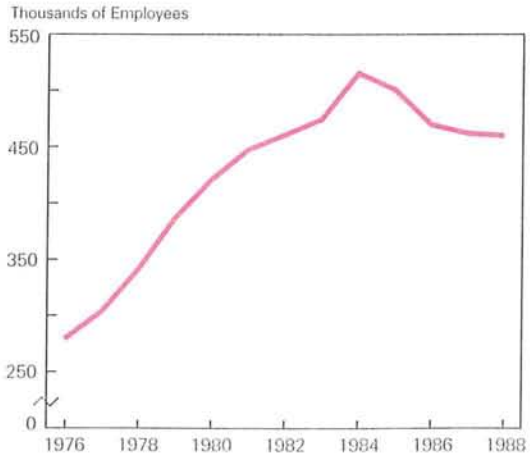


Figure 2

U.S. employment in the computer industry increased over time.[a]



[a]Employment shown is for SIC code 357, "Computer and Office Equipment."

Source: U.S. Bureau of the Census.

[1] Products and models in the PC market are used interchangeably.

[2] For a more detailed analysis of this topic, see Stavins (1995).

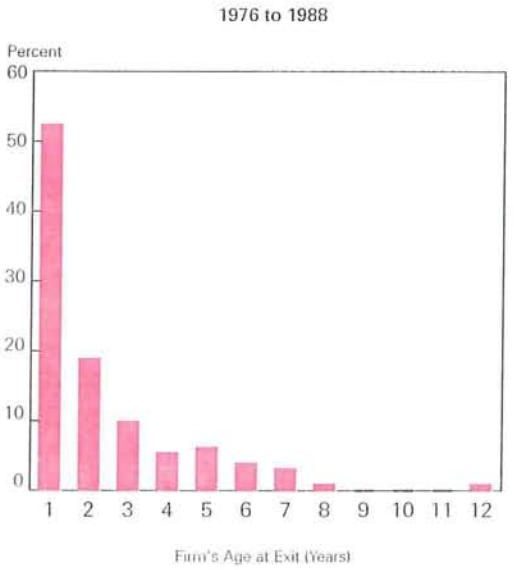
[3] The Herfindahl index is defined as a sum of the squares of the market shares of all the firms included in a particular market.

porate their own components that are difficult or impossible to imitate (for example, because of patent protection). In the PC market, few such technical barriers to entry were present. Existing technology typically has been widely available and components often manufactured by other firms. Despite the seemingly easy entry into the market, however, firm entry and new product introduction required sunk entry costs, such as establishing retail channels and advertising. With the continuously evolving market, few companies managed to survive in the market beyond one or two years. As Figure 3 shows, the majority of exiting firms were only one year old.

In industries with firms producing several different products such as PCs, individual firms need to decide which *models* to introduce, not just whether to enter or leave a given market. The situation becomes even more complicated in the case of firms producing several products. Incumbent firms introducing new products must decide whether to replace their old models with similar new ones (possibly "cannibalizing" their own products) or to enter new segments of the market. In other words, firms decide where to place their new models in a "space" of existing products. Such spatial location decisions might be intended to deter entry by other firms. Industries with firms producing several different goods allow for analysis of entry and exit of products, and of strategic behavior on the part of their producers.

Figure 3

Few firms survived beyond their first year.



II. *Theoretical Background*

In the PC market, a decision about which models to offer for sale is strategic, not simply technological. PC components are, to a large degree, produced by firms other than those that sell complete systems. Indeed, the technology embodied in microprocessors and storage devices can be assumed to be available to any firm at a given time. Each firm chooses which models it is going to offer, subject to the constraints imposed by existing technology. Incumbents face a choice:

(1) They can place all their models in a single segment of the market, by locating their new models close to their existing ones. The strategy allows firms to take advantage of their "local" scope economies[4] but at the same time creates substitutes for their previous models. This strategy results in market segmentation, where each firm produces only close substitutes.

(2) They can try to preempt the entire market by placing their new models further away in product space. That way they avoid cannibalizing their existing models and occupy empty market niches before entrants do. This strategy leads to market interlacing, where various firms' models alternate.

If existing firms choose the first strategy, they may steer customers away from their own existing products in favor of their new products. But entering new market segments is more risky, as it entails incorporating new technology before it is established in the market and accepted by consumers.

In the PC market, existing firms have significant advantages over potential entrants. For example, consumers are more likely to buy familiar brands, and older firms may have long-term contracts with distributors, lowering their costs relative to those of new firms. Because of such considerations, new entrants may be forced to search for empty market segments to avoid price wars with more established firms. Hence,

[4] Economies of scope exist when it is cheaper to produce several products jointly than each one separately. For example, it may be cheaper to produce screws and nails together than each in a separate establishment, since the bulk of the investment (factory, machines, labor) has already been made.

incumbents would be expected to distribute their models along the entire spectrum to make entry by new firms difficult.[5] Under this scenario, incumbents' models will be more dispersed in product space than new entrants' models.

III. Previous Research

Beginning with Hotelling's (1929) model of spatial location (see the box), several theoretical models of entry deterrence and preemption in a multifirm market have been developed. In Hotelling's model, two identical firms locate next to each other along a line. The results change in the case of heterogeneous firms, sequential entry, and companies producing several products, but few analyses deviate from the standard assumptions.

The results of the theoretical studies are inconclusive. While some support the market segmentation scenario, others conclude that market interlacing is more likely. The results depend heavily on the assumptions of specific models, such as number of competitors, order and timing of their entry into the market, whether they produce one or more goods, and whether the products are identical or differentiated. The market segmentation results are shown in Schmalensee (1978) and in Eaton and Lipsey (1979). In Schmalensee (1978), the market was dominated by a small number of colluding firms, which localized their brands in order to deter entrants most effectively. In Eaton and Lipsey's (1979) model, an incumbent monopolist in a growing industry introduces a substitute for his own product before an entrant does, in order to preempt the market.

Market interlacing results from the models of Bonanno (1987), Spence (1976), and Brander and Eaton (1984). Bonanno (1987) showed that with no threat of entry, existing firms would locate as far away as possible from each other. If they faced a threat of entry, incumbents would deter entrants by greater product dispersion, in order to create competition in all market segments and make entry unprofitable. In Spence's (1976) model, a firm would not offer substitutes for its own product, as that would lower demand for its existing commodity. The firm would opt for more distant products instead. Brander and Eaton (1984) showed that with no entry, a segmented market structure yields higher profits, but a possibility of entry reverses the result.

The theoretical results are thus inconclusive. Empirical analysis is clearly required, but no previous empirical papers have measured the degree of model dispersion by firms.

Hotelling's Model of Spatial Location

The idea of spatial location of firms began with Hotelling's (1929) model. In his model, two ice cream vendors (1 and 2) decide where to locate along a single street. The vendors are identical in all respects (they offer an identical product at the same price), except for their location. Every block has the same number of consumers, each buying one ice cream cone. Consumers care only about proximity to the vendor—they always buy from the nearest one.

In the picture below, person A will prefer to buy from vendor 1, while person B will choose vendor 2. Person C, located equally far from the two vendors, is indifferent between them. Where should the vendors locate to maximize their profits? Each wants to be closest to the highest possible number of consumers, whatever the location of the other vendor. Each vendor also assumes that the other will remain in his current location. In the picture below, vendor 2 would locate just to the right of vendor 1 (because then everyone to the right of vendor 1 would buy from him), while vendor 1 would locate just to the left of vendor 2 (because then everyone to the left of vendor 2 would buy from him). As a result, the two vendors would get closer and closer to each other. In the end both vendors would locate in the middle of the street, each serving half of the city residents. The Hotelling model explains why fast food vendors and gasoline stations often locate on the corners of the same intersection. Although Hotelling used geographic space, his model could also be applied to characteristic (quality) space and the location of individual products in that space.

[5] Some theoretical studies predict that an existing firm producing several products will preempt the entire market with its own products. See, for example, Prescott and Visscher (1977), Eaton and Lipsey (1979), Eaton and Kierzkowski (1984). However, since it is costly to introduce new models, incumbents must limit the number of models they market.

IV. Description of the Data

The data set includes annual prices and technical attributes for new personal computers sold in the United States from 1976 to 1988.[6] For each observation, the data include a set of technical specifications and a price, as well as each model's name and its producer. Table 1 lists the major attributes and their descriptive statistics.

Table 1
Summary Statistics for Major Variables, 1976 to 1988

PC Variable	Mean	Std. Deviation	Min.	Max.
Price (dollars)	2726	2119	40	13995
RAM Memory (KB)	500.7	496.4	.5	4096
Clock Speed (MHz)	7.75	4.81	.5	25
Hard Disk Capacity (MB)	15.58	34.48	0	314
Number of Floppy Drives	1.07	.61	0	3
Number of Slots	4.72	3.72	0	22
Dummies:				
16-bit Processor	.480	.500	0	1
32-bit Processor	.124	.329	0	1
B&W Monitor	.408	.492	0	1
Color Monitor	.028	.166	0	1
Portable	.156	.363	0	1
Additional Hardware	.018	.134	0	1
Discount Price	.278	.448	0	1

The definition of a model changed over time. Initially, models did not carry discrete options for memory, storage capacity, and the like; rather, models had fixed specifications. Towards the end of the sample period, however, most models could be custom-ordered with alternative configurations of memory, speed, and hard disk capacity. However, firms still had to make the strategic decision of whether to introduce a new model or continue the old one with new specifications. Introduction of a new model carries a fixed cost of a new design, marketing, and dealer arrangements. The sample has 134 firms and 472 models.

V. Measuring Quality

Personal computers are vertically differentiated products, composed of a variety of characteristics.[7] Each attribute is measured in different units. To compare locations of many different models in an imaginary product "space" (similar to Hotelling's street), it is necessary to adjust for differences along several dimensions. This study summarizes the most important attributes in a single "quality" measure. After each model is assigned a quality measure, the models' location along a line can be compared. Each PC model m is assigned a single-dimensional quality q_m, equal to the weighted sum of its specifications z_{jm}, (with $j = 1, \ldots, J$), with weights β_j:[8]

$$q_m = \sum_{j=1}^{J} \beta_j z_{jm} \qquad (1)$$

The weights β_j should represent the marginal value that consumers and producers place on the j^{th} attribute, which can be approximated by the estimated marginal implicit prices from a hedonic regression (see the box).

Hedonic Regression

Table 2 reports hedonic regression estimates of coefficients on major technical attributes, producer dummies, and age of each model, based on how they contribute to real prices of personal computers.[9] For each model m, produced by firm i in year t, the hedonic regression is:

$$\ln P_{mit} = \beta_0 + \beta_i + \beta_t + \beta_1 \ln(\text{RAM}_{mit}) + \cdots + \beta_j \text{AGE} + \cdots + \varepsilon_{mit} \qquad (2)$$

where β_j ($j = 1, \ldots, J$) indicates an estimated coefficient on the j^{th} characteristic. Most coefficients on the technical attributes are positive and statistically significant, indicating that adding an extra unit of storage (hard disk), memory (RAM), or speed (MHz) raises

[6] The data were originally collected by Cohen (1988) and later updated by Kim (1989). Sources include technical model reviews in June issues of *Byte*, *PC Magazine*, and *PC World* for list prices and attributes, as well as ads in the Business section of June Sunday issues of *The New York Times* for discount prices.

[7] Products are said to be vertically differentiated if all consumers agree on which products they prefer when all the prices are equal. For example, most consumers would choose a Cadillac over a Chevy if their prices were the same. By contrast, products are horizontally differentiated if the optimal choice depends on consumer taste. For example, some consumers would choose a red car, while others may prefer a blue one.

[8] The index is a valid approximation of the correct quality if product characteristics are separable, that is, if a change in one characteristic does not affect the impact of other characteristics on quality. See Triplett (1987) for details.

[9] "Real prices" indicates prices in 1982 dollars.

Hedonic Estimation

Hedonic regression is used to estimate the relationship between product prices and the attributes of respective products. The estimated coefficients on attributes in the hedonic equation represent marginal implicit prices of each attribute. For example, to find out how much more would be paid for an additional cubic centimeter of engine capacity in a car (how much the market has judged that cubic centimeter to be worth), one could estimate a regression of automobile prices on engine capacity, size of wheelbase, number of cylinders, horsepower, a set of dummy variables indicating whether a car has anti-lock brakes, power doors, and air conditioning, as well as its make. A coefficient on the engine capacity variable would indicate the price of an additional unit of capacity, holding all the other measures constant.[10] Similarly, in the case of personal computers, a hedonic coefficient on clock speed indicates the implicit price of an additional megahertz of speed, even if units of speed are not offered for sale. Hedonic coefficients represent the value attached to each attribute by the market, encompassing both demand for a particular characteristic and the additional cost a company has to incur to add an extra unit of that attribute. Hedonic coefficients are used as weights for the quality measure shown in equation (1).

the price of a PC. Strong brand effects also show up: PCs manufactured by major firms command a higher price than similar machines that carry lesser, unknown brand names, controlling for other attributes. The reason for the brand effect is that reputation and name recognition may raise the established firms' value to consumers. By contrast, year dummies (which indicate the average difference in price between each year and 1976, controlling for other attributes) have negative coefficients. The estimated coefficients on year dummies indicate that PC prices dropped sharply year after year, controlling for quality and brand effects. In earlier research, Berndt and Griliches (1993) found that quality-adjusted prices of PCs declined by an average of 28 percent per year.

[10] See, for example, Griliches (1971 and 1988) for a discussion of hedonic estimation.

Table 2
Hedonic Regression of PC Prices on Attributes,[a] 1976 to 1988

Variable	Coefficient	t-Statistic
Intercept	6.517	47.60
log (Hard Disk)	.164	19.64
log (RAM)	.336	18.10
log (MHz)	.228	5.82
log (Number of Floppy Drives)	.370	7.98
log (Number of Slots)	.087	4.38
Model Age	.055	3.95
Attribute Dummy Variables:		
Black & White Monitor	.068	2.53
Color Monitor	.126	1.93
Discount Market	−.274	−9.86
Extra Equipment	.222	2.68
Portable	.224	5.66
16-bit Processor	.248	7.24
32-bit Processor	.575	9.59
Producer Dummy Variables:		
Apple	.181	2.67
Atari	−.561	−7.66
Commodore	−.388	−6.23
Compaq	.338	6.51
IBM	.037	.75
NEC	.140	2.25
Radio Shack	−.010	−.45
Zenith	.244	3.78
Wyse Technology	.040	.54
Epson	−.117	−1.53
Kaypro	.098	1.18
NCR	.319	4.04
Northgate	.192	1.94
Year 1977	−.572	−3.45
Year 1978	−.823	−4.77
Year 1979	−.924	−5.85
Year 1980	−.985	−6.44
Year 1981	−1.212	−7.79
Year 1982	−1.452	−9.46
Year 1983	−1.918	−12.80
Year 1984	−1.948	−12.89
Year 1985	−2.375	−15.30
Year 1986	−2.799	−17.76
Year 1987	−3.125	−19.62
Year 1988	−3.501	−21.45
R^2 = .759	F = 115.7	N = 1436

[a]Dependent variable is log (Real Price), where prices are measured in 1982 dollars. The omitted firm category is "Other."

Quality Space

To reduce several attributes to a single-dimensional measure, a single number representing quality was assigned to each PC model. Quality was mea-

sured as a weighted sum of each model's attributes, such as storage, memory, and speed. The attribute weights, β_{jt}, were derived from the hedonic estimation described above. Since implicit prices of technical attributes of PCs declined significantly over the period covered by the data, a separate hedonic regression was estimated for each year. The equation in Table 2 is therefore illustrative only and represents average coefficients on attributes over time.

VI. Entry

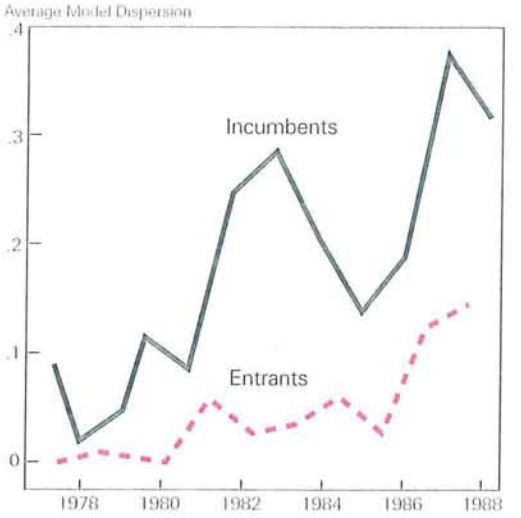
Both incumbent and entering firms make strategic spatial location decisions when they introduce new models into the market. Existing firms try to keep potential new entrants away, that is, to deter future entry. In industries where each firm produces a single product, the optimal strategy is for firms to distribute themselves evenly in the product space so as not to leave any empty spaces for new entrants.[11] Such a strategy is most likely to prevent potential entrants from coming into the market. But in the case of firms that produce several different products, such as the PC industry, an existing firm must decide where to place its new models relative to the existing models, taking into account not only potential entrants' products, but also possible effects on the demand for its own products.

Dispersion among Models

A measure of within-firm model dispersion was constructed to test the hypothesis that incumbents spread their new models along quality space more than entrants.[12] For each firm, the within-firm dispersion measure was compared with overall dispersion in the PC market in that year to obtain a measure of relative dispersion—that is, the degree to which a firm's models were dispersed in the quality space relative to those of other firms.

Figure 4

Incumbent PC firms show higher dispersion in model quality than entrants.



As can be seen from Figure 4, incumbents had a consistently higher model dispersion than new entrants, consistent with the hypothesis. The dispersion was also higher for older firms, on average, as can be seen in Figure 5. The difference could not be attributed to the fact that new firms introduce fewer models; the dispersion measure controls for the number of models, and firms that came in with only one model were not included in the dispersion analysis (they had no dispersion).

Econometric estimation was used to determine whether dispersion changes continuously with the age of firms or asymmetry exists between entrants and incumbents, and whether firm experience accumulates with years on the market or with the number of models a firm has produced. Table 3 shows the estimated relationship between the relative dispersion index and a set of factors that might explain firm decisions regarding the spatial location of their models.

Older firms ($FIRMAGE_{it}$) with more model expe-

[11] See, for example: Bonanno (1987); D'Aspremont, Gabszewicz, and Thisse (1979); Hay (1976); and Schmalensee (1978).

[12] σ_{it} is a measure of within-firm dispersion:

$$\sigma_{it} = \frac{\sum_{m=1}^{M_{it}} (q_{mit} - \bar{q}_{it})^2}{M_{it}}, \text{ where } \bar{q}_{it} = \frac{\sum_{m=1}^{M_{it}} q_{mit}}{M_{it}},$$

q_{mit} is quality as described in equation **(1)**, and M_{it} is the number of models produced by firm i in year t. σ_t is the total dispersion of all the models in year t:

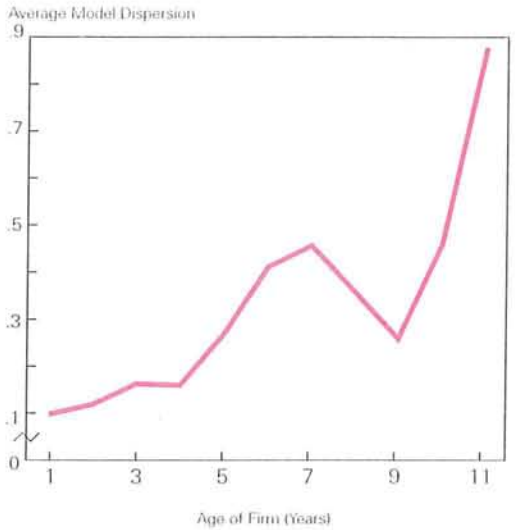
$$\sigma_t = \frac{\sum_{n=1}^{N_t} (q_{nt} - \bar{q}_t)^2}{N_t}, \text{ where } \bar{q}_t = \frac{\sum_{n=1}^{N_t} q_{nt}}{N_t},$$

and N_t is the total number of models produced by all firms in year t ($N_t = \Sigma_i M_{it}$). R_{it} is the relative dispersion index: $R_{it} = (\sigma_{it} / \sigma_t)$. Only firms with at least two models on the market were considered in the dispersion analysis.

Figure 5

Older firms dispersed their models more.

1976 to 1988



rience were indeed more likely to have higher model dispersion and thus to "cover" the whole quality spectrum. The result is consistent with persistently strong brand effects in the PC industry. Once a firm established brand recognition, it utilized it to cater to all market segments. For example, once Zeos got a reputation for its quality and service, it diversified by introducing more advanced models, such as portables.[13] At the same time, the established firms continued their production of technologically "obsolete" models, thereby expanding their model spectrum over time.

Regardless of a firm's age, the more "experience" it had (as measured by the number of models it had marketed in the past, $NMODCUM_{i,t-1}$), the more dispersed were its models. The effect may be due to the fact that the more models a firm produces, the more established is the firm's reputation and the larger are its cost advantages due to economies of scope. Those advantages were reflected in the firm's strategic decision to disperse its models through product space.

Table 3

Relative Model Dispersion[a]

Variable	Coefficient	t-Statistic
Intercept	−.017	−.29
$ENTRANT_{it}$	.043	.90
$FIRMAGE_{it}$	.051	4.23
$PIONFIRM_i$	.102	1.88
$NMODCUM_{i,t-1}$	.019	2.98
$NUMFIRM_{t-1}$	.001	.75
Number of observations		323

[a]Dependent variable is $R_{it} = \sigma_{it}/\sigma_t$, a relative dispersion index for firm i in year t. ENTRANT dummy equals 1 if firm is an entrant; FIRMAGE is firm's age; PIONFIRM dummy equals 1 if firm is "pioneering," that is, if it ever produced a model incorporating frontier technology; NMODCUM is number of models firm has introduced before current year; and NUMFIRM is number of firms in previous year. More details can be found in Stavins (1995).

"Leapfrogging"

A popular belief is that new entrants in high-tech markets "leapfrog" existing firms by being first to introduce the most advanced technology. This hypothesis was tested for the PC industry by comparing quality of new models introduced by incumbents and entrants. If the popular belief were true, new firms would be the ones to introduce the most advanced technology. As Figure 6 shows, however, the opposite turned out to be true in the PC market: On average, new models introduced by incumbents were of higher quality than those introduced by new entrants. Thus, while existing firms were typically first to offer the most technologically advanced products, new firms located their models in more established market segments. New firms may not be able to afford the risk of being first in new market segments.

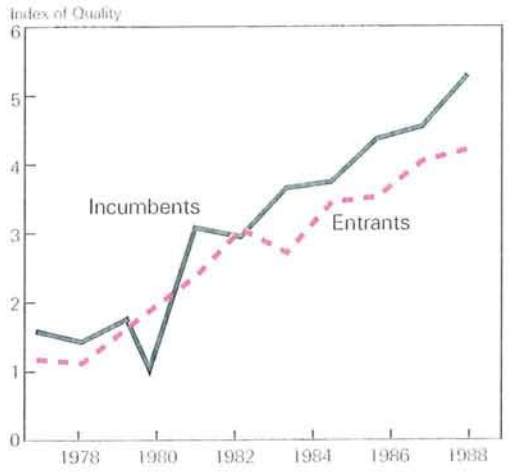
VII. Exit

Despite the industry's growth since its beginnings in the 1970s, firms and models have continually left the market. Some firms' models may tend to stay in the market longer because of those firms' reputations or economies of scope due to learning effects. But model exit can also be due to individual model effects; a model may be overpriced relative to other models

[13] Similar effects can be observed in other markets. For example, once Cuisinart established its reputation as a maker of food-processors, it took advantage of the brand recognition and began marketing other products, such as pots and pans, with a Cuisinart label.

Figure 6

Incumbents introduced higher-quality models than entrants (on average).



with similar attributes. Regression analysis can quantify how important the two types of effects were in inducing the exit of PC models from the market during the 1976–88 period.

Firm Effects

Firm-specific reasons for model exit may be related to the firms' order of entry into the market. They may be associated with what Schmalensee (1982) called "pioneering brands." He showed that coming in early pays off: Customers are more likely to continue buying the brand they recognize, even if a new entrant introduces a cheaper version of the same product. If costs of switching away from incumbent producers in the PC market turn out to be high, new entrants' models would fail to gain market share and would tend to leave the market first. Brand loyalty is more likely to attach to firms than to individual models, since with rapidly advancing technology customers are unlikely to make repeat purchases of the same model.

A firm's long market tenure (due to outstanding management, for example) also gives it a potential advantage of accumulated experience. Likewise, previous investment in advertising and R&D may make a firm's models more likely to remain in the market than similar models by other firms.[14]

Model Effects

To account properly for the firm effects and to test whether established firms had advantages over new entrants in model exit, individual model effects have to be controlled for. Previous work supported the idea that higher-priced models have something customers are willing to pay for, even if the "something" cannot be observed in available data (Trajtenberg 1990; Berry, Levinsohn, and Pakes 1995). However, high prices may also indicate that a particular model was simply overpriced given its attributes. Since coefficients on model attributes in a hedonic regression represent both costs of production and valuations of attributes by consumers, those coefficients can be used to calculate a predicted model price, with which the actual price can be compared.[15] The difference can have two distinct interpretations: (1) a markup of price over cost, thus measuring over- or underpricing of a model; or (2) some unmeasured quality of a model. These differences are used here as a measure of relative overpricing of PC models (holding their attributes constant) to test whether overpriced models are more likely to exit the market.

Analysis

On average, models that exited the market had higher prices relative to prediction than models of the same age that stayed for at least one more year (Table 4). However, firm-related factors also appear impor-

Table 4

Exiting Models Had Higher Price-Cost Markups, 1976 to 1988

Did the model exit that year?	Average Difference Between Predicted and Actual Price (Price-Cost Markup)
Yes	.05
No	−.04

[14] A firm's models may leave the market simply because the firm goes out of business. In order to isolate that effect, this study separately analyzed models produced by continuing firms only.

[15] The difference between the actual and predicted prices is equal to the hedonic residuals.

tant in determining exit, with incumbent firms having an advantage over new entrants: As Table 5 shows, over 40 percent of the models leaving after their first year on the market were produced by new firms. Over one-third of the models that left after their first year were produced by new firms that themselves left the market. The causality of events could go in either direction: Firms might have exited because of their poor management and high costs, but they also might have left because their models were inferior.

The probability that a model exited in a given year was estimated (in logit form) as a function of firm and model characteristics, including measures of model overpricing (Table 6). The coefficient on the difference between predicted and actual price (RESID) is both positive and significantly different from zero, indicating that the difference captures model overpricing rather than unmeasured value to consumers, and that overpriced models are indeed more likely to exit the market. The second variable, however, indicates that the marginal effect of the difference diminishes as the difference gets bigger (plus or minus).[16] The size of these two coefficients can be interpreted as follows: If a firm doubles the price of its model without changing the model's attributes, its likelihood of exiting rises. How much it rises depends on its previous likelihood of exiting: If the model's likelihood of leaving the market was 0.25, doubling the price will raise it to 0.33; if it was 0.5, it will be 0.6; and if it was 0.75, it will now be 0.82.[17] When an interaction term of ENTRANT and RESID was included in the model, the coefficient was positive. That indicates that when new entrants

Table 6
Probability of Model's Exit,[a] 1976 to 1988

Variable	Coefficient	t-Statistic
Intercept	−.285	−1.50
$RESID_{mit}$	1.421	3.56
$RESSIGN_{mit}$	−1.142	−2.23
$FIRMAGE_{it}$	−.115	−2.91
$ENTRANT_{it}$	.440	2.16
$MODELAGE_{mit}$	.211	3.25
$NMODCUM_{i,t-1}$	.095	5.86
$PIONFIRM_i$	−1.586	−7.61
$PIONMODEL_{mi}$	.367	1.15
N	1092	
chi^2	133.04	
log likelihood	−681.14	

[a]Dependent variable is the probability of exit of model *m* by firm *i*, in year *t*. RESID is residual from annual hedonic regressions; RESSIGN is signed residual square (+ for positive, − for negative); FIRMAGE is firm's age; MODELAGE is model's age; and NMODCUM is number of models firm has introduced before current year.

Table 5
Exit of Models and Firms from PC Market, 1976 to 1988

Over 40% of models that left the market in their first year were produced by new firms . . .

Firm's Age	Number of Models	Percent
1	112	41.79
2	38	14.18
3	35	13.06
4	25	9.33
5	25	9.33
6	14	5.22
7	3	1.12
8	11	4.10
9	2	.75
11	3	1.12
Total	268	100.00

. . . and most of those firms left the market themselves

Age of Firm at Exit	Number of Models	Percent
1	99	36.94
2	43	16.04
3	39	14.55
4	26	9.70
5	26	9.70
6	14	5.22
7	4	1.49
8	12	4.48
9	2	.75
11	3	1.12
Total	268	100.00

[16] The difference between positive and negative residuals is captured by the signed residuals squared (RESSIGN, $+\varepsilon^2$ for positive residuals, $-\varepsilon^2$ for negative ones). Since the signed residuals squared coefficient is negative, the residuals' effect diminishes as its absolute value grows larger.

[17] If a firm doubles the price of its model without changing the model's attributes, the hedonic residual on the model will increase by 0.693. Because the probability of model's exit is estimated using the logit model, it follows that

$$\frac{\Pr(\text{exit})}{\Pr(\text{no exit})} = e^{x\beta}.$$

An increase in the residual by 0.693 will in turn translate into an increase in the model's probability of exit from the market relative to the previous probability of exit:

$$\Pr_1(\text{exit}) = \frac{1.5\ \Pr_0(\text{exit})}{1 + 0.5\Pr_0(\text{exit})}.$$

overprice their models, they increase the likelihood of their models leaving the market even more than that of incumbents that overprice.

The FIRMAGE coefficient is negative and significantly different from zero, indicating that older firms' models are less likely to exit than younger firms' models. Two explanations of the advantage are possible: Either the longer the firm has been on the market, the lower are its costs (due to learning effects),[18] or consumers develop brand loyalties and buy models manufactured by firms they trust. If the former is true, a firm's costs decrease as the firm gets more established. In that case, an older firm's models would be cheaper and the difference between predicted and actual price lower. Since no such difference exists between newer and more established firms, the brand loyalty explanation for firm effects seems more plausible than the learning effect theory. Furthermore, new entrants' models are more prone to exit the market even controlling for firm's age, as shown by the positive and significant coefficient on the ENTRANT dummy.

Brand loyalty and reputation apparently allow firms to compete successfully in the market despite some overpriced models.

Another interesting question is whether selling overpriced models makes a *firm* drop out of the competition. There is no evidence for that: The correlation between a firm's overpricing and its probability of exit or its number of new models is not significantly different from zero. Thus, brand loyalty and reputation apparently allow firms to compete successfully in the market despite some overpriced models.

VIII. Summary and Conclusions

Following developments in the personal computer industry over time is no easy task. The industry has undergone tremendous changes with technological innovation and new product development, and continuous movement of firms and products into and out of the market. What can be learned from observing those changes? Does firm behavior follow certain patterns? Which firms are first to embody the most advanced technologies in their models when initially developed: existing firms or new entrants? Do firms preempt the market by gathering all their products in a single segment of the market, or do they disperse them along the product space?

This study uses data on prices and attributes of individual PC models sold in the United States between 1976 and 1988 to analyze patterns of model entry and exit. Application of hedonic coefficients as weights on individual model characteristics allows computer models differentiated in many attributes to be projected onto a linear quality scale. Such a linearization allows comparisons of model selection across different firms and over time. Contrary to popular belief, the findings indicate that new entrants do not "leapfrog" existing firms in the introduction of new technology. Incumbent firms offer the most technologically advanced products, while new entrants locate in more established market segments. At the same time, incumbent firms take advantage of their brand recognition and continue offering their older models. As a result, incumbents' models tend to be more dispersed throughout product space than entrants' models.

Firm effects were also significant in determining the probability of a model's exit. In particular, older firms were more likely to keep their models from leaving the market. New entrants were particularly vulnerable; their models were more likely to exit the market than other firms' models, even controlling for overpricing and firms' age. The study also finds that overpriced models are more likely to exit the market, regardless of the age and experience of their producers.

Despite large differences among PC models, persistent firm effects were documented in all parts of the study. Those effects cannot be explained by the models' characteristics. Firms gain their advantage over time; the older the firm, the more likely it is to be successful. The advantage could be due either to learning effects (tenure on the market lowers firms' costs) or to firms' reputations stemming from brand name recognition. This study found no conclusive evidence for the learning effects, but strong evidence that established firms gain brand name advantages. The results show that established firms use their

[18] Because model-specific fixed costs decrease with the number of models introduced (due to increasing returns to R&D, advertising, and retail agreements, for example), the older the firm, the lower are its costs of model introduction. The decrease in costs associated with cumulative output is consistent with Lieberman's (1984) result.

advantage to preempt the market by dispersing their models along quality space.

Those results shed light on firms' behavior in industries with firms producing several different products. Brand recognition is very strong, even in such a rapidly evolving market as the PC industry. Therefore, firms should benefit from aggressive marketing strategies early on. Once their brands are established and their names recognized, they may try to redeem some of the early investments. On the other hand, consumers are more likely to get better deals by buying products manufactured by new entrants, which often offer promotions and discounts to get their foot in the door.

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