R&D patterns in the video display terminal industry

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This is the peer reviewed version of the following article:

Link, A.N., & Zmud, R.W. "R&D Patterns in the Video Display Terminal Industry," *Journal of Product Innovation Management*, 1984, 1(2): 106-115. https://doi.org/10.1111/1540-5885.120106

Abstract:

A long-standing question asks whether small firms or large firms are more successful in product innovation, and the answer seems to be coming up, "It depends." Professors Link and Zmud reveal some of the things it depends on when they describe the results of their research on the VDT industry. They see the VDT industry as a possible prototype of the several technologically progressive industries now growing toward the early stages of maturity. What we see here today may be a forerunner of what we'll see elsewhere in the near future.

Keywords: video display terminals | R and D | high-technology industries

Article:

Introduction

Various aspects of technological change and innovative behavior have been studied in some respects for over 100 years. The more recent empirical literature on this subject has generally focused on cross-sectional (firm and industry) investigations of the inputs to and the outputs from the innovation process [13]. More recently, studies have considered the direct linkage between investments in innovation and resulting technological growth [1]. While these studies have been useful, their contributions toward predicting innovative behavior in any one industry are only as valid as is a comparison of R&D activities *across* industry bounds. Although fewer in number, industry case studies have also provided useful insights into aspects of the overall innovation process [9, 23, 25]. These case studies are particularly useful since an ability to predict industry specific technological behavior is demanded by increasing policy efforts to adopt broadly based programs for stimulating innovation [21].

This article reports the findings from an examination of innovative behavior in the video display terminal (VDT) industry. We present empirical evidence to support existing ancedotal evidence of industry activity. Specifically, we test hypotheses about the influence of firm size on various aspects of innovative activity—R&D spending, innovative output, and the use of alternative sources of technical information. Although the VDT industry is small in terms of its contribution to GNP, it is perhaps a prototype of an important cadre of rapidly maturing, technologically progressive industries—such as solar energy, biogenetics, and microelectronics—now developing within our economy. Therefore, the results of this study may add empirical insights for theoretical models of the evolution of technology based industries.

The VDT Industry

A VDT consists of a cathode ray tube (CRT), a keyboard, information processing circuitry, and possibly embedded software. These products evolved in the early 1970s as a replacement for the teletype terminal to improve direct human interaction with computer systems. The United States industry currently consists of about 200 manufacturers with total sales in 1982 over 3.4 billion, an installed base of over 6.5 million units, and present growth rates (units sold) of 20-25% per year [3, 6].

The industry can be characterized briefly as follows. First, there is a high degree of seller concentration (a five-firm concentration ratio of 40% and a ten-firm concentration ratio of 60%) and a very low degree of buyer concentration [14]. Second, there is rapid technological change (e.g., new products, new product features, expanded product capabilities, etc.) occurring within the industry. Evidence of this fact is represented not only by the industry's intense R&D activity but also by the fact that product life cycles are, on average, less than three years. Third, although relatively concentrated on the sellers side, there are few barriers to entry into this industry. Fourth, there appear to be substantial barriers to survival. Innovation seems to be occurring as a continuous stream of incremental enhancements rather than as radical technological breakthroughs. Since most innovations are either quickly imitated or are not accepted in the market place, a sustained R&D program is requisite for corporate success [14, 15]. This importance of R&D is especially troublesome for the smaller firms who successfully enter the market with an innovative product and then strive to sustain this performance over the long run. While innovative products are frequently rewarded by a rapid growth in sales, efforts to exploit this demand require the firm to shift financial resources to production and customer servicing. As a result, R&D (especially long-term R&D) may suffer. When larger firms begin to imitate the successful product offerings of these smaller firms by offering improved lower-cost versions, the smaller innovating firms will rapidly lose market shares (or even exit from the industry) unless their R&D has been strategically directed.

There are three major submarkets in the VDT industry: dumb, smart, and intelligent terminals. In 1979, dumb terminal sales accounted for 27% of total sales with smart and intelligent terminals accounting for 58 and 15%, respectively [14]. Dumb VDTs, often referred to as "glass teletypes," possess little, if any, internal processing capabilities. The first generation of dumb VDTs introduced in the early 1970s sold for between $1000 and $2500, depending on external features. Technological advances in the mid-1970s reducing the number of discrete components required in manufacturing, along with economies of scale in production, have reduced the price of second generation units to between $400 and $500. Prices are now relatively stable and there appears to be little further potential for drastic cost reduction without radical technological breakthrough. The dumb VDT segment can best be described as a mature industry with competition taking the form of advertising which stresses product features. R&D activity in this submarket tends to be product related and defensive in scope. Most of the technological innovation associated with this submarket occurs outside the firm in the form of purchased components such as CRTs and microcircuitry.

Smart VDTs are configured with internal circuitry enabling prespecified internal processing such as line editing and data entry operations. This is also a maturing market having recently experienced its "shake out" stage [15]. With prices set initially around $3000, competition and experience has now driven prices as low as $600. The smart terminal is expected to be the "workhorse" terminal of the 1980s, with competition emphasizing price, product capabilities, and vendor services. With continuing price competition within the smart VDT submarket and the decreasing expense associated with incorporating "smart" capabilities into dumb VDTs, the smart and dumb submarkets are beginning to merge [6]. Likewise, as features are added to smart terminals (improved ergonomics and more internal circuitry), they will begin to compete with intelligent VDTs.

Intelligent VDTs provide sufficient internal circuitry, storage, and software such that sophisticated information processing can be performed locally. With the inclusion of a compiler or interpreter, a machine's local capabilities can be revised or extended by acquiring compatable software packages. At present, this is still an immature industry with evolving technologies and differing product prices ($2500 to $8000 depending on features), but the industry appears to be entering the growth phase of its life cycle [15]. While this growth is directly confronted by the personal computer [5, 6, 10, 15, 19], it is likely that personal computers and intelligent VDTs will continue to compete on the basis of specific user-defined market niches. Product competition with intelligent VDTs is expressed in terms of new technical features, improved software, and color graphics. R&D in this market is offensive and is directed toward achieving these goals. Unlike the dumb and smart terminal markets, major technological breakthroughs often occur in this submarket as a result of inhouse R&D (as opposed to product suppliers' R&D).

The above description of this industry is based entirely on anecdotal evidence and broad industry statistics. The empirical study which follows represents an effort to validate this portrait, particularly with regard to disparate innovative activities within the industry's submarkets.

The Study's Background and Methodology

One hypothesis frequently tested regarding the R&D-to-firm size relationship is that R&D spending increases more than proportionately with firm size owing to the financial ability of larger firms to support and sustain a successful R&D program. Kamien and Schwartz [13] have reviewed these studies and conclude that the empirical evidence, aside from the chemicals industry [12], does not support this proposition. Several possible explanations may be given. First, many of the studies are based on cross-sectional samples of firms from heterogeneous industries. R&D activities encompass a myriad of activities ranging from basic research to product development on one spectrum, or from short-term applied to long-term risky on another spectrum. It is difficult enough to compare R&D programs between two firms within the same industry or market owing to these compositional differences, much less to compare total R&D spending across industries. Second, there is a selection bias associated with many of the samples. R&D data are only published (by McGraw-Hill or Compustat) for those firms who have maintained an established, and presumably successful, R&D program. This probably means that the firms studied are the larger firms in the industry and perhaps those whose growth has entailed product diversification (which makes R&D even harder to define and to relate to one particular outcome). Third, few studies have separately analyzed the relationship between firm size and the composition of R&D. There are, however, two notable exceptions. Both Link [16] and Mansfield [18] have examined R&D by its character of use and have concluded that the composition of R&D is quite important when estimating the R&D-to-size relationship.

The present study involved contacting 221 organizations believed to have been associated with the VDT industry in 1981. As no complete listing of industry members was uncovered, this collection of possible VDT manufacturers was compiled primarily from product announcements and advertisements. Research instruments were then sent to 78 organizations who were, in fact, active in the industry and who agreed to participate in the research project. Usable responses were ultimately received from 34 of these firms. Firms not included within this sample of 34 organizations were those who did not manufacture VDTs, those no longer in business, those no longer manufacturing VDTs, those reluctant to release the requested information, and those unable to provide the requested information.[1] Firms unable to provide information generally fell into one of two categories: large diversified manufacturers who organized their R&D around technologies rather than products (and hence were unable to isolate VDT R&D activities), and small manufacturers who simply had not gathered the requested information. IBM's VDT activities, while they may account for as much as 20% of industry sales, are conspicuously absent from our sample. IBM as well as the other computer industry giants were included in the initial set of firms.

Although the number of firms in the sample is small, they accounted for about 60% of 1981 sales in the industry. Our sample contains a wide range of alternatively sized firms, $50,000 to $190 million (mean is $18.6 million), and a wide range of R&D spending patterns (and perhaps R&D strategies), $4000 to $11 million (mean is $1.16 million). Also this sample contains firms active in each of the three industry submarkets. Generally, however, one firm is not active in all three submarkets. Nine of the organizations specialized completely in a single submarket, and the remaining firms have the majority of their sales in either the dumb/smart submarkets or the intelligent submarket.

Although employing such a limited sample of manufacturing firms might possess limitations, the tighter control of contextual and environmental factors that results is advantageous when contrasting the innovative activities of such disparately-sized organizations. The following sections of the paper will present our research models and findings regarding the relations among firm size, industry submarket, and three categories of R&D behaviors: firm spending for a

[1] A listing of the firms included in our survey and a copy of our survey instrument is available upon request.

variety of R&D activities (innovation inputs), the introduction of new products (innovation output), and the use of alternative information channels (innovation sources).

R&D Spending

Four regression models are analyzed to estimate the relationship between R&D spending in total and by type, and size of firm. The R&D-related variables are: RD—the organization's total R&D expenditures; B—its expenditures on basic research; LTR—its expenditures on long-term risky research; and JV—joint venture research outside the industry. Firm size is quantified as the organization's gross VDT sales, SALES.

Based on the previous empirical studies referenced above we expect there to be a positive relationship between SALES and each of the four dependent variables. All of these data came from our survey, and refer to 1980 (measured in millions of dollars).

R&D spending, based on our sample data, is on average directed toward the short-term and development ends of the R&D spectrums. Only 1.7% of 1980 R&D was directed toward basic research with 21.5% going to applied and the remainder going to development. Similarly, 8.2% of R&D was allocated to projects viewed as long-term and risky while 50.9% went to short-term applied activities. Also, the development of most projects was internal, 82.4% as opposed to being jointly developed with an outside firm.

Also included in these regression models is a second independent variable, the percentage of each VDT organization's sales from the separate submarkets. This variable, MKT, was measured as the percentage (between 0 and 1) of sales in the intelligent terminal market. We are thus implicity treating the dumb and smart terminal submarkets as a single submarket. This formulation is consistent with our earlier description of this industry's R&D behavior.

We expect that more R&D, in total and by type, will be done by firms in the intelligent terminal submarket. In the intelligent market, where no dominant product design has yet emerged, competition exists in terms of the continued introduction of successful technology-based innovations. Therefore, it is not unreasonable to expect that relatively more R&D will be conducted and that a greater portion of that R&D will be toward the basic and long-term risky end of the R&D spectrums. Also, since this is an immature industry, we expect firms to engage more willingly in joint research ventures with firms outside the industry in order to both reduce costs and speed the innovation process. Therefore, the estimated coefficient on the variable MKT is predicted to be positive in each regression model.

The specific regression models analyzed here are as follows:

$$\ln \mathrm{RD} = \alpha_0 + \alpha_1 \ln \mathrm{SALES} + \alpha_2 \mathrm{MKT} + \epsilon_a, \tag{1a}$$
$$\ln \mathrm{B} = \beta_0 + \beta_1 \ln \mathrm{SALES} + \beta_2 \mathrm{MKT} + \epsilon_b, \tag{1b}$$
$$\ln \mathrm{LTR} = \gamma_0 + \gamma_1 \ln \mathrm{SALES} + \gamma_2 \mathrm{MKT} + \epsilon_c, \tag{1c}$$
$$\ln \mathrm{JV} = \eta_0 + \eta_1 \ln \mathrm{SALES} + \eta_2 \mathrm{MKT} + \epsilon_d, \tag{1d}$$

where all forms of R&D expenditures and firm size are measured as logarithms. This type of log-linear specification allows the estimated coefficient on SALES to be interpreted directly as an elasticity measure. (Such a formulation is consistent with the previous research cited above.) As stated, we expect $\hat{\alpha}_1$, $\hat{\beta}_1$, $\hat{\gamma}_1$, and $\hat{\eta}_1$ to be positive. Also, we predict $\hat{\alpha}_2$, $\hat{\beta}_2$, $\hat{\gamma}_2$, and $\hat{\eta}_2$ to be greater than zero.

The least-squares regression results for Eqs. (la)-(ld) are reported in Table 1. The empirical findings are consistent with our predictions: firm size is significantly correlated with total R&D spending in the VDT industry. However, the estimated size elasticity of R&D ($\hat{\alpha}_1$) is statistically less than one, implying that larger firms do spend more on R&D than smaller firms. but not proportionately more relative to their size. (Similar results were also obtained when 1979 sales were used as the regressor. One should, however, be careful not to impute causality from this limited one year lag structure.) The same is true for each of the three categories of R&D spending. In no case was there evidence that R&D spending by category of use was proportionately greater in larger sized firms. This finding can be interpreted as indicating that R&D resource allocation does suffer on a relative basis as market successes require a VDT organization to increasingly direct its attention to non-R&D activities.

Table 1. Least-Squares Regression Results from Eqs. (1a)-(1d)[a]

	Regression Coefficients on		
Dependent Variables	**ln SALES**	**MKT**	R^2
ln RD	0.54 (4.61)[b] [–3.86][b]	1.03 (1.92)	0.55
ln B	0.49 (3.23)[b] [–3.34][b]	1.26 (1.81)	0.39
ln LTR	0.63 (2.86)[b] [–1.67]	2.15 (2.13)[c]	0.37
ln JV	0.35 (1.91) [–3.49][b]	1.99 (2.34)[c]	0.29

[a] Numbers in parentheses are t statistics to test the null hypothesis that the parameter equals zero; in brackets are t statistics to test the null hypothesis that the parameter equals one.
[b] 0.01 significance level.
[c] 0.05 significance level.

The estimated coefficients on MKT are all positive, as predicted, and are all significant at the 0.10 level or better. In other words, firms specializing in producing intelligent VDTs are, holding firm size constant, more active in total R&D activity and especially in those categories of R&D which are believed to be more highly associated with major technological breakthroughs and long-term growth.

New Product Introduction

While there have been many studies examining the relationship between firm size and R&D spending, only few have considered the impact of firm size on innovative output. The reason for the paucity of research on this topic is due perhaps to a lack of published data quantifying the outputs from innovative activity. Some researchers survey the number of major innovations by firms over some time period or count patent applications or issues in order to define a firm's innovative outputs. Kamien and Schwartz [13] have reviewed these studies and have concluded that, beyond some modest level, firm size is not conducive to the completion of innovational activities. (Again, the experience of chemical firms seems to be an exception to this generalization.)

To examine the relationship between firm size, SALES, and the innovative output of each VDT organization, IO, we again estimated a log-linear regression model. The dependent variable representing innovative output was measured as the total "number of new VDT products introduced in 1979, 1980, and 1981 which are directly related to the use of an advanced technology not previously applied." (The mean value of IO is 5.9 innovations with a standard deviation of 6.9.) Firm size is measured in this equation as total 1979 (base year) gross VDT sales. We predict a positive relationship between SALES and IO. Although we believe that smaller firms may initially introduce innovative products, larger firms quickly initiate these successful products such that their *total* number of new products (over a three year period) is probably greater.

As before, the percentage of each firm's sales in the intelligent terminal market (MKT) is held constant in the regression equation. We predict the impact of this variable to be positive because, as discussed above, intelligent terminals are produced in an immature industry where competition occurs primarily on the basis of successful product innovation. The total number of new products introduced should consequently be greater by organizations who primarily compete in this market, *ceteris paribus.* Also, as was shown in the previous section, firms in this market are relatively more intense in R&D spending toward the basic and long-term ends of the R&D spectrum. It is not unreasonable to expect that these kinds of R&D activities are more likely to result in the introduction of new products.

A third independent variable is also considered in the regression equation to capture the effect of managerial input into the innovation process. The primary motivation for capturing managerial inputs to the innovation process was to use this factor as a control variable in assessing the effects of firm size and submarket specialization. Specifically, respondents were asked the number of years of experience in (a) their current position, (b) in their VDT organization, (c) in the VDT industry, and (d) in R&D activities in general. Each of these experience measures (EXP) was used in separate versions of our research model. We predict a positive relationship between IO and EXP on the basis that experience represents a form of human capital investment and that innovative output (as we have measured it) is one product of this investment.

Specifically, the regression model examined is:

$$\ln \mathrm{IO} = \alpha_0 + \alpha_1 \ln \mathrm{SALES} + \alpha_2 \mathrm{MKT} + \alpha_3 \mathrm{EXP} + \epsilon \tag{2}$$

The least-squares regression results, with EXP measured as years in current position, are:

$$\ln IO = 0.52 + 0.136 \ln SALES + 0.35\, MKT + 0.08\, EXP; \qquad (3)$$

(1.82) (2.48)* (1.84) (2.71)*
[–15.71]

$R^2 = 0.51$.
(*0.01 significance level)

The estimated size elasticity of innovative output is positive, and is significantly different from zero (t statistics in parentheses). It is also significantly less than one (t statistic in brackets). As in the case of R&D spending, innovative output increases less than proportionately with firm size. Also, as predicted, firms selling in the intelligent terminal market introduce significantly (at 0.10 significance level) more new technologically induced products than firms in the dumb/smart terminal markets. The R&D manager's tenure in his current position is also a significant (at the 0.01 level) determinant of R&D success. When the three other measures of job experience were considered, however, the estimated coefficients were positive but none were statistically significant. It appears, therefore, that in the VDT industry the skills and judgments necessary for innovative success (but. not necessarily commercial success) are gained in-house in the same job position. Knowledge obtained from general organization, industry, or R&D experience does not appear to be as important, in a statistical sense, in determining interfirm differences in innovation output.

Alternative Sources of Technical Information

In this section we examine the relationship between firm size and the acquisition of R&D information by VDT organizations. Specifically, two sources of technical information are considered. The first is an internal source, the use of the VDT organization's own marketing group. The second is an external source, the use of consultants or universities. Our intention here is to quantify the extent to which each source of information is used by the R&D group for acquiring R&D intelligence.

Our first regression model examines the relationship between firm size, SALES, and the probability of use of the organizations' marketing group, MG, as a source of technical information. We do not expect larger firms to make relatively more use of marketing as a source of R&D intelligence for two reasons. First, smaller firms are generally less compartmentalized than larger firms, so they may better enjoy an organizational structure conducive to interdepartmental information flow. Thus, a negative relationship between size and the use of marketing would be expected. Alternatively, one may argue that since the VDT industry is R&D competitive, and since once a firm successfully enters the industry its survival is a function of its innovative activity, then all firms are equally likely to use all of their internal resources. Thus, no relationship between size and the use of marketing would be expected.

In a similar fashion as the prior two sections, we also include in this equation MKT to assess the influence of industry submarkets on the probability of each organization making use of its marketing group. We predict that organizations producing in the intelligent terminal market to use marketing relatively less than those organizations producing in the dumb/smart markets. As we have discussed, competition in the dumb/smart markets is primarily through advertising and

R&D leading to improved product features. Whatever product improvements do occur, we expect them to be demand induced through the marketing group.

The dependent variable, MG, in this regression model is dichotomous, equalling 1 if the organization "always or very often" (as measured on a Likert scale) uses its marketing group for R&D intelligence and 0 otherwise ("sometimes or never"). Therefore, a logistic probability model is used for the estimation:

$$\mathrm{MG} = 1/[1 + \mathrm{e} - (\alpha_0 + \alpha_1\mathrm{SALES} + \alpha_2\mathrm{MKT} + \epsilon]. \tag{4}$$

As stated, we do not expect $\hat{\alpha}_1$ to be positive but have reasoned that $\hat{\alpha}_2 < 0$.

The logit results from Eq. (4) are reported in Table 2. Firm size has a negative, though numerically small, impact on the probability of a firm making significant use of its marketing group for R&D intelligence. The calculated partial derivative implies that a $I million increase in sales decreases the associated probability by 0.07 percentage points. This finding may suggest that as a VDT organization grows, its R&D function becomes more specialized, and thus its R&D division experiences less interaction with other organizational units. This interpretation is not inconsistent with our earlier assertion that as a VDT organization achieves market success, its R&D function undergoes an organizational deemphasis relative to certain other functions. The estimated coefficient on MKT is also negative and significant. The corresponding partial derivative is rather large: a 1% increase in intelligent terminal sales decreases the probability of marketing interaction by 82 percentage points. Presumably, marketing's role is one leading to demand induced (market driven) innovations.

Table 2. Logit Results for the Probability of Using Marketing as a Source of R&D Intelligence

Dependent Variables	**Logit Coefficients**[a]	**Partial Derivatives**[b]	**OLS Coefficients**
SALES	–0.19	–0.0007	–0.004
	(–2.81)[c]		
MKT	–15.30	–0.82	–0.76
	(–5.01)[c]		
–2 × Log Likelihood Ratio	27.3		

[a] Asymptotic t statistics are reported in parentheses.
[b] Evaluated at the mean.
[c] 0.01 significance level.

The second source considered for acquiring R&D technical information is the frequency of using consulting firms or universities. There is a developing literature on the use of formal technical information (usually in published journals) by R&D personnel. This literature tentatively suggests that smaller firms acquire less outside technical information for R&D decision making than do larger firms owing to their limited managerial resources [7]. This conclusion is reasonable when the information sought is not intended to be firm specific. However, in the case of a firm appropriating R&D intelligence for competitive purposes, an opposite conclusion might be reached [8, 20]. In a sense, by examining the frequency with which a VDT organization makes use of consultants or universities for R&D intelligence, we are examining the firm's choice to internalize one aspect of innovative activity or alternatively to make use of some existing market mechanism (consultants or universities). In a broad sense, one may view this decision in terms of Coase's [4] analysis of a firm's nonmarket activities. For a related empirical test see Bozeman and Link [1] or Link, Tassey, and Zmud [17].

Given the technological-based competition characterizing the VDT industry, we expect larger firms to internalize their innovation process to a greater degree than smaller firms. Also owing to the importance of long-term, basic types of research for survival in the intelligent terminal market, firms in this submarket may employ an in-house research staff with greater technical expertise than the staffs employed by firms in the dumb or smart terminal submarkets. If so, this would reduce their need to use an outside market, like consultants or universities, to acquire technical knowledge.

Using a logit specification similar to the model represented by Eq. (4), we test for the relationship between firm size, SALES, submarket, MKT, and the use of consultants or universities, CU, as a source for R&D intelligence (CU = 1 if these sources are used "always or often," and CU = 0 otherwise). As stated, we predict $\hat{\alpha}_1 < 0$ and $\hat{\alpha}_2 < 0$. The logit results are reported in Table 3. These findings support our first hypothesis: larger firms do make less use of external sources of R&D technical intelligence than do smaller firms. While there is no statistical evidence (at a conventional level of significance) that the use of these external sources is related to a firm's participation in a specific VDT market segment, the sign of the regression coefficient is consistent with our prediction. These results suggest that R&D groups in larger firms are less likely than those in smaller firms to promote communication exchanges with internal or external bodies. While such behavior might be explained by numerous phenomena, two that directly follow from increasing size seem most likely: an inevitable evolution toward bureaucratic organizational forms which inhibit both inter- and intra-organizational information flows; and, the availability of resources enabling R&D units to internalize information gathering activities.

Table 3. Logit Results for the Probability of Using Consultants and Universities as a Source of R&D Intelligence

Dependent Variables	Logit Coefficients[a]	Partial Derivatives[b]	OLS Coefficients
SALES	–0.29	–0.007	–0.003
	(–4.19)[c]		
MKT	–1.82	–0.06	–0.15
	(–1.46)		
–2 × Log Likelihood Ratio	20.2		

[a] Asymptotic t statistics are reported in parentheses.
[b] Evaluated at the mean.
[c] 0.01 significance level.

The findings regarding the effect of industry submarkets, while still consistent with the research hypotheses, are not as dramatic. One explanation of why the submarket variable is not as significant as might be expected follows directly from the immature nature of the intelligent terminal submarket. If a dominant product design has yet to appear, technology rather than consumers are driving product development—hence, the negative relationship regarding marketing group communications. This relatively high level of technological uncertainty regarding technology with intelligent terminals, however, might very well lead some manufacturers to develop external linkages with consultants or university researchers even given the competitive advantages of completely internalizing R&D activities.

Conclusion

While any conclusions drawn from this analysis must be tempered by the study's limitations (its small sample size, the absence of at least one key industry participant, and the potential for response bias and response ambiguity with survey-based research), it is noteworthy that our findings are consistent with anecdotal descriptions of the VDT industry [14, 15], with studies of other high-technology industries [11, 22], and with generally accepted theories relating product life cycles and industry structures [24]. These data consequently provide empirical support for the ideas introduced in these related streams of thought which, in general, lack documentation.

More specifically, these findings illustrate some important patterns in the R&D behaviors of firms in rapidly maturing, high-technology industries such as the VDT industry. A particularly interesting aspect of the VDT industry at the time data was collected was that one of the industry's primary submarkets involved a relatively mature product line while the other submarket involved an immature product line. By assessing and then contrasting the R&D behaviors within these two submarkets, an understanding of the appropriateness of particular R&D behaviors within the VDT industry emerges.

In the mature dumb/smart VDT submarket, R&D projects tend to be directed toward incremental, market-induced product innovations. Such behavior seems very rational given that few, if any, major technical breakthroughs are expected with the current generation of dumb/smart VDT technology and that any which do arise tend to occur outside the industry (via component suppliers) or within the industry's larger firms (whose innovativeness can perhaps best be characterized as imitative). With the less mature intelligent VDT submarket, R&D is of a relatively longer-term and more risky nature, reflecting a more intensive technological competition among manufacturers. Even here, however, larger firms engage in more R&D and seem to enjoy greater overall technological success.

While larger firms exhibit greater R&D activity, the marginal returns of increasing size are significantly less than proportional. This observation, along with the finding that larger VDT organizations seek less technical R&D information from both internal (marketing) and external (consultants and universities) sources, suggests that pressures accompany a VDT organization's growth that internalize and, to a relative extent, isolate and deemphasize R&D. Since market successes usually require a VDT firm to invest heavily in both capital stock and personnel resources, this relative deemphasis of R&D (particularly that of a long-term nature not directly related to current products) is not surprising. VDT industry observers, however, contend that in order for firms to achieve initial and continued market success they must simultaneously commit themselves to extensive marketing and R&D efforts [14, 15]: parallel with marketing a proven product, firms must actively engage in developing enhanced product versions as well as replacement products. Support for this dependence of industry success on an understanding of both technological and market forces was indicated by the finding that a R&D manager's tenure in directing firm-specific R&D activities, rather than general firm, industry, or R&D activities, was positively related to technidal R&D success.

While concerns naturally arise with any attempt to generalize empirical findings from one specific industrial setting to broader implications applicable to a set of related industries, the consistency between these findings and other descriptions of high-technology industries leads us to comment on what appear to be three important issues regarding the management of R&D activities for rapidly maturing, high technology product lines.

First, the combination of a rapidly changing technological base and short product life cycles seems to promote the formation of discrete industry submarkets, each of which reflects a different "generation" of the dominant technologies associated with a product line. As the factors which contribute most significantly to market success within such submarkets will likely vary according to the maturity of a submarket's product line, quite distinct organizational skills and strategies should characterize the behaviors of firms competing in different submarkets. Aside from the largest firms within the industry, it is further expected that most firms will primarily compete within a single submarket because of the considerable organizational overhead required to compete effectively in more than one submarket. If organizational skills and strategies are tightly bound to product line life cycles in rapidly maturing, high-technology industries, one might expect to observe a relatively high exit rate from the industry. This, in fact, seems to be the case with the VDT industry.

Second, the different competitive environments of each of the submarkets within a rapidly maturing, high-technology industry will be characterized by distinct patterns of R&D activity. A submarket manufacturing a relatively mature product line would quite rationally experience less R&D activity aside from that induced through market, rather than technological forces. A submarket manufacturing a relatively immature product line would quite rationally both engage in more R&D activity, particularly that of a technological nature, and tend to internalize these activities.

Third, given a market environment characterized by rapidly maturing product lines, by very knowledgeable consumers, by an ease of product imitation, and by the heavy use of procured components, it is to be expected that R&D strategies would be skewed toward short-term projects directed at current products. All high-technology industries, nonetheless, require R&D of a longer term and more risky nature. With VDTs, for example, the successful development of technologies such as flat panel displays, improved power supplies, and improved touch and voice input capabilities, among others, are very likely to promote new generations of products across all of the industry's submarkets. As discussed above, most firms competing in the VDT industry are not extensively engaged in longer-term R&D efforts directed toward developing technologies such as these. A number of related questions arise for which our study provides no answers. Should all the firms in such industries be committing scarce resources to such longer-term R&D endeavors? Should firms in more mature submarkets rely on those firms in immature submarkets to develop the technologies that apply equally well across all submarkets? Should such an industry rely on its suppliers (who as well supply industries manufacturing substitute products) and its largest members (who rationally delay introducing technological developments as long as is competitively viable) to develop new technologies? Essays or empirical research which provide insights toward answering such questions are particularly encouraged.

As a final note, it is interesting to recognize the increasing number of joint ventures and cooperative dealings among high-technology firms [2]. Most of these arrangements, however, are directed for competitive reasons toward basic research rather than the promotion of technological advancements of a more applied nature such as those representative of major VDT technological breakthroughs. Is it desirable, or even possible, for firms in rapidly maturing, technologically progressive industries to develop similar cooperative arrangements when the R&D efforts involved would be targeted specifically at end-product competition? With the growth in the number of products across all industries that are becoming dependent on high-technology component parts, it is very likely that industry R&D patterns such as those characterizing the VDT industry will begin to appear across many other industries. As this occurs, the pressures for developing solutions to the questions we have raised will intensify. It is our aim that this article stimulates the search for such solutions.

Acknowledgements

An earlier version of this paper was presented at the microeconomic workshop at Yale University where it benefited from the comments of the participants, especially Richard Nelson and Richard Levin. Also, many useful suggestions have been provided by William Fischer, Edwin Mansfield, John Neufeld, Greg Tassey, Eleanor Thomas, and Eric von Hippie. We would also like to acknowledge the many helpful points raised by the reviewers.

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