THE FINANCING THRESHOLD EFFECT ON SUCCESS AND FAILURE OF BIOMEDICAL AND PHARMACEUTICAL START-UPS

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Abstract

This study applies the theories of technological innovation to the process of formation and growth of biomedical and pharmaceutical firms. It is based on detailed data gathered from 26 firms, founded between 1968 and 1975 in the Commonwealth of Massachusetts. These data were supplemented by a three-member expert panel evaluation of the risk associated with use of each firm's products.

A positive relationship was established between the level of technological sophistication of the firm and the risk associated with use of its products. Consequently, technological advancement of the firm has not necessarily resulted in high economic performance, in part because of the high demands put upon the firm's resources and time by the U.S. Food and Drug Administration approval process.

The study indicates that the initial financial inputs have a threshold effect on subsequent economic performance of biomedical and pharmaceutical new firms. In the sample studied, unless these inputs reached the $850,000 to $1,000,000 mark (in 1970-1975 dollars), technological innovation was negatively mediated by the risk associated with the use of firm's products and by the FDA quality control procedures. Consequently, attempts at technological innovativeness are unfortunately detrimental to economic performance of new and underfinanced firms in the biomedical and pharmaceutical industry.

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2 Our gratitude goes to Professor Stan Finkelstein of MIT and to the entrepreneurs who shared their experience and insights with us.

Technology, Risk Associated with Use, and the FDA

The literature of technical entrepreneurship points to the importance of the main resources of a new technical enterprise - technological know-how and financial resources (Roberts, 1968; Pankiewitz, 1980; Taylor, 1981; Utterback et al., 1983; Van de Ven et al., 1983).

Recent work by Roberts et al. (1981) attempt to extrapolate from the research base of non-biomedical industries to set a structured research agenda for the biomedical field. The conceptual model (Figure 1) presented by Moskowitz et al. (1981: 3-5) articulates the progression of technology from ideas to products and practices, and the interactions among people which facilitates this flow. These processes operate in a specific regulatory and marketing environment, which determines to great extent their structure, direction and intensity.

Figure 1 approximately here

A related research perspective is based on the theories of technological innovation and their diffusion. The classical opus in this area by Coleman, Katz & Menzel (1966) exemplifies this approach. More recent studies by Bernstein, Beaven, Kimberley, and Moch (1975), and Leonard-Barton (1983) use similar premises and empirically validate the paradigm of diffusion of medical innovations as a two-stage communication process. Related studies focus on the relation between basic research and its application in medical practice (Comroe and Dripps, 1977). The Committee on Technology and Health Care of the National Academy of Science (1979) provided rich conceptual background

for the analysis of equipment-embodied medical technologies though most of the theoretical analysis is based on cursory empirical data.

The extensive regulatory constraints imposed by the Food and Drug Administration (FDA) emerge as one of the most significant differences of the biomedical industry vis-a-vis other technology-based industries. The extent of this external interference and control of quality standards is overwhelming, including both the efficacy and the safety of the product (pars. 510-515, FDA, 1976). The regulations also include directions about manufacturing and record-keeping procedures (par. 501), and labeling and advertising standards (par. 502). Both sets of standards are far more rigorous than standards which apply to nonbiomedical industries. The structure of FDA regulations partitions the product areas of the biomedical industry into drugs and pharmaceuticals, medical devices, and para-medical products and supplies. The latter two categories were first regulated by Congressional action in 1976.

Ashford, Butler and Zolt (1977), Young (1982), and Wardell (as cited in Roberts, 1981) analyzed the pharmaceutical industry and the influence of the FDA on its productivity and innovativeness. Another direction followed by Fuchs (1974), Measday (1977), and Temin (1979) focused on the changes in the pharmaceutical industry, historically analyzing the interaction between technology and the regulatory environment. Temin's study focused more on the economics of this industry. More recently Birnbaum (1984) assessed the strategic responses of firms in the X-ray equipment manufacturing industry to increasing regulation. These studies present strong evidence for the significance of the interplay between the regulatory constraints, and the innovativeness in this industry.

Wardell (1974) points to the fact that extensive regulations in the U.S. decreased research productivity as measured by the number of new chemical entities (NCE) presented to the FDA for approval. He also showed (as cited in Young, 1982) that between 1962 and 1971 Britain led with respect to drugs available in both nations, calculated in terms of drug-years of prior availability. Britain also "..possessed nearly four times as many exclusively available drugs as did the United States" (Young, 1982, p. 19), mainly because the regulatory constraints there have not been as severe as in the US. Moreover, "This over-regulation had increased drug industry costs, driven a great deal of research overseas or into safer generic areas, slowed or blocked the release of useful drugs"[our emphasis]. The amendment to the FDA Act in 1962 is described by Young (p.19) as "therapeutic disaster". Ashford et al. (1977) voice the same sentiments with some reservation related to the complexity of cost-benefit analysis of the impact of the FDA regulations.

Recently, Finkelstein and Homer (1984) directly addressed the issues of FDA policy decision-making in the face of the trade-off between the public benefits from novel medical technologies, and the higher risks associated with their use. They show how sensitively a new medical technology's utilization might be influenced by government regulations. Their computer-simulated comparison between the regulated and the unregulated environment encountered by a new implantable heart pacemaker technology shows that heavier regulations might delay the product's technical evolution by as much as one and a half years, and somewhat inhibit its sales growth during the first 12 (!) years after the new technology is introduced.

All these suggest that technological attributes of medical in-

novations are associated with the extent of FDA influence on their development; this relation is obviously mediated by the risk associated with the use (RAWU) of the product which embodies the technological attributes. On the other hand, the intensity of the FDA's regulatory constraints is a strong determinant of the time and costs resulting from the federal approval process. Consequently, the financial requirements for founding a biomedical firm must go beyond the normal requirements of a new technology-based start-up, in order to weather potentially prolonged periods of commercial inactivity caused by the rigor of the FDA evaluation process.

The small and comparatively young biomedical firm, founded by an entrepreneurial individual or group, with the explicit objective of commercializing a product or technological knowhow, is the junction of numerous processes. It contains all the stages of biomedical innovation, from idea generation through to its communication, utilization and development, and up to its diffusion into practice.

Determinants of Success and Failure of New Biomedical Firms: Research Questions and Hypothese

The estimated volume of the U.S. biomedical and pharmaceutical industry is quite significant, approximately 25 billion dollars in 1980 (Gibson et al., 1983; Frost and Sullivan, 1983). Yet no research documents the role or issues of the young firm within this industry. The research questions addressed in this paper stem directly from the studies of the pharmaceutical industry and its innovations, and the gaps in the ad hoc research pertaining to that industry: a) What is the interaction between technological sophistication of a young biomedical firm's products and the financial resources at its founding

in determining its economic success? b) To what extent do the FDA regulations impact technologically novel biomedical products and the firms that generate them?

Our main hypothesis is that the interaction between the technological innovativeness of a biomedical firm and the scale of its financial resources in determining its economic success is somewhat complex. The logical steps in modelling this process are threefold:

Because:

H1: Technologically novel biomedical products, especially those featuring new or first-of-a-kind technologies, or having special specifications, generate higher perceived risk associated with their use;

Then:

H2: The impact of FDA regulations is more significant for technologically novel biomedical products;

Consequently:

H3: Only those firms which mobilize adequate financial resources are able to benefit economically from their technological innovativeness. Inversely, the attempts of inadequately financed firms to launch technologically novel products are detrimental to their economic peformance.

Sample Selection and Data Collection

The sampling procedure used in this study differs to some extent from those used in prior studies of new firms (e.g., Roberts, 1968; Taylor, 1982; Utterback et al., 1983; Meyer and Roberts, 1984). Although our sample was clearly purposive, we attempted to make it as complete as possible.

Our assumption was that the data pertinent to our hypotheses would be available from firms with several specific attributes. First, the firms should be approximately one decade old, to allow sufficient time since incorporation so that their commercial performance is of a more stable pattern, after the initial start-up turmoil. On the other hand, to facilitate collection of first-hand data directly from the founders, the firms should not be older than 15-20 years, which age would increase the probability of founders' death or relocation, or of change of ownership since incorporation.

Second, the firms should have been formed for the purpose of doing business in the biomedical or the pharmaceutical industry, to present a more focused picture about young company operations in this specific area. Multi-product conglomerates clearly do not fit this requirement.

Third, to present as much as possible a comprehensive picture of the biomedical industry, the firms should be vertically integrated from R&D to marketing. Consequently, the firm should be an independent legal entity, not an R&D, manufacturing, or marketing arm of a larger corporation.

Adhering to the above criteria, the process of sample selection and data collection consisted of several stages. First, corporations whose names suggested either a medical, pharmaceutical, biological, or a general technical context were selected from the 1970 to 1975 Massachusetts State House incorporation records. Next, those firms which either did not have the required vertical integration, were previously incorporated outside Massachusetts, or did not actually operate in the biomedical or the pharmaceutical industry were screened out on the basis of direct review of their original records of

incorporation in the State House registry.

Second, the founders of the relevant firms, including those which had been dissolved, were located, to the extent possible. Third, the research questionnaire was tested with the target population, modified from earlier work used by Roberts and Wainer (1971), Taylor (1981), and Utterback et al. (1982). The main factors that were tested were the time required to complete the expanded questionnaire and the relevance and clarity of the new questions related to the medical context. The final research instruments consisted of a self-administered questionnaire, containing mainly well-structured and simple questions, and an interview questionnaire, containing unstructured or complicated issues which required real-time clarifications or explanations.

Fourth, founders' agreements to participate were secured. Among those who were not willing to participate at this stage the common explanation was "Don't want to talk". As much as the specific causes could be traced, they were usually "preoccupation with the current problems of the firm", or "the experience was too painful to walk through it again for research purposes".

Fifth, the self-administered questionnaire was mailed to 32 founders of biomedical firms (in addition to the pilot study) of which another 7 dropped out for various reasons. Some of the reasons that were mentioned: "I'm too busy with my clinical research in X University"; "The firm does not exist anymore"; "The questionnaire is too long"; "He does not have the time, and he doesn't want to talk" (secretary); "Although I'm willing to participate, I'm leaving for business negotiations to Europe till the end of March".

Sixth, field interviews with 25 founders were conducted,

usually in their office. The founders of firms that were dissolved were interviewed at their homes or at the offices of their present employer.

Seventh, in addition to the data about the risk associated with use of their products that was collected directly from the entrepreneurs, we decided, due to the potential importance of this variable for causal analysis, to independently assess product risk by use of external experts.

Sample Evaluation

Three firms were screened out of the sample, two of them due to confounded background or inadequate data and another because it had actually been incorporated in the early sixties.

For the analysis of entrepreneurial background and the initial period of founding the firm, 28 cases were used, while for the detailed causal analysis, 26 cases were included. One of the 26 cases lacked data about entrepreneurial background, early founding, and financing.

The final sample included three firms from the pre-test, for which the data were collected in a slightly different format. Two firms that were actually incorporated in 1968 and 1969 were included in the sample, as representative of the agglomerates of firms founded by the same founders between 1965 and 1975.

It was not possible in all the cases to obtain the necessary information about the comparative performance or the product area of the firms which dropped out of our sample. As far as we can tell attrition biases are not significant. We know that at least one dropped-out firm has approximately 400 employees, and another is a

successful producer of heart pacemakers. Two firms were active in the product area of drugs and pharmaceuticals and at least two were in auxiliary products.

We assume the attrition of firms which were dissolved, or encountered severe operational difficulties, was comparatively high. At least one firm was under FDA investigation and could not participate in the study for legal reasons. Drugs and pharmaceuticals were represented among the "drop-outs" (about 4-5 firms), but the distinction between medical devices and auxiliary products, based on the limited data in the State House objectives of incorporation, was more difficult to make.

Other reasons for attrition included firms being acquired by large conglomerates or relocated to other regions of the U.S. For instance one firm had been undergoing acquisition by a Texas corporation, two relocated to Florida and California, and two founders had just recently died (see summary in Appendix A).

On the other hand, we would contend that the firms included in the sample are representative of the population of medical instruments firms, as described by Dorfman (1982) and by Hekman (1980). As also can be seen from the above anecdotal information about the reasons for self-elimination from the study, the firms that were excluded were of a broad range of sizes and of economic performances (see Appendix B for sample attributes). The breakdown by year of incorporation of the sample selection and the data collection stages is summarized in Table 1.

Table 1 approximately here

Indicators and Measures

Technological attributes of the firm

The various technological attributes of each firm's products were evaluated by the entrepreneurs on quasi-Likert* ordinal scales. The aggregate indices of technological sophistication of a firm's products were computed by summing up (across products) the scores on the scales of the importance of "new technology or first of kind", "special purpose or special specifications", and "calibre of product or personnel" as competitive advantages of a firm's products. The reliability of the additive indices based on the above three measures for each of the products of the firms was sufficiently high to justify their use as a measure of a single construct. (Cronbach's alpha between 0.53 and 0.57*.)

To derive the product specific technological index the above three scales were aggregated for each product separately (the alphas for the three products ranged between 0.50 and 0.60). The index of overall technological sophistication of the firm was derived by summing up the product specific indices and was found to be highly reliable (alpha=0.70).

Assessment of risk associated with use (RAWU)

The use of a panel of experts has been recommended for assessment of risk associated with use of novel technologies (Fischhoff,

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* For detailed discussion see:
Miller, D. C. (1983). Handbook of research design and social measurement (4th edition). Longman, NY & London; Novick. M. R., & Lewis, C. (1967). Coefficient alpha and the reliability of composite measurements. Psychometrika, 32, 1-13.

Lichtenstein, Slovic, Derby, & Keeney, 1982). The size of the panel (three members) corresponds to the recommendations of Libby and Blashfield (1978) and Rohbaugh (1979), who showed that increasing the size of the panel beyond three members offers only incremental improvements in reliability.

Our panel comprised three MDs in the early stages of their professional careers, who, independently of each other, estimated the risk associated with use of each firm's products. The dimensions that were evaluated by the panel included risk to the medical personnel and to patients associated with use of the products, the invasiveness of the products, and the products' proximity to the clinical high impact area of the industry.

The panel supplied its assessment of the RAWU as scores on quasi-Likert ordinal scales. The raw scores of the panel were aggregated consecutively on three levels: a)for an additive scale of the three panel members, which yielded a Cronbach alpha of 0.91; b)for an additive scale of the scores on "Risk associated with use to the patient" and the "Invasiveness" for each product, which yielded Cronbach's alphas between 0.92 and 0.96; and c)for the overall risk associated with use index of the firm, derived by summing up the product specific indices, which yielded a Cronbach alpha of 0.98. Starting from the second level of aggregation of the raw scores RAWU the resulting indices were treated as interval variables. (See Appendix C for descriptive statistics of the RAWU.)

The impact of the FDA regulations

The impact of the FDA regulations on firm's operations was estimated by two independent indicators: a)the reported impact of the

FDA regulations on firm's operations and management decision-making, and b)the estimate of the out-of-pocket expenses precipitated by the requirements of the FDA interactions.

Measurement of economic success

The evaluation of economic success is an interesting issue; several studies in the past used quite simple indicators of commercial success of new firms. Meyer and Roberts (1984) argue that growth rate of sales alone is not reliable because it is biased towards the fast growing young firms. They divided the growth in sales by the age of the firm, using an aggregate of the last two years to smooth for annual fluctuations.

Taylor (1981, 15-16) used growth rates of sales as a measure of economic performance, although he partitioned his sample into "relatively successful" firms, "..if [they have] average sales growth that places [them] in the top half of the sample, and if [they have] been profitable in at least two of the past three years" (p. 15), and "relatively unsuccessful" if they have not. It should be noted, though, that Taylor's sample has a wide distribution of the start-up year: from 1960 to 1981. This factor presents acute problems of control for his study, especially for causal analysis. The Meyer and Roberts sample spans eight years of corporate birthdates (1968-1976), compared with six years span for most of the firms in the sample used in the present study.

The significance of firm's age as a determinant of its sales was tested and the results could not reject the null hypothesis of no difference. On the other hand, to smooth temporary fluctuations of sales, we used the average of the annual sales between 1980 and 1983

as the indicator of firm's commercial success. This index was highly correlated with the 1983 market value of the firm, as estimated by the entrepreneur (R=0.92), with the average number of firm's employees for the same four years (R=0.95), and with the growth in annual sales (R=0.95), validating its possible use as a single measure of firm's success.

Results

Technology and risk associated with use

The first in our chain of hypotheses was that technologically novel products will be concomitantly of high risk associated with their use. According to our findings (Table 2), the strongest indicator of technological novelty of firm's products - "new technology or first of a kind" is positively associated with the RAWU

Table 2 approximately here

score of each firm's products. On the other hand, the average novelty of a firm's product specifications or purpose, and the calibre of firm's products or personnel, do not contribute to higher risk associated with their use. This finding, in addition to proving the main point of technological newness-RAWU association, also suggests a less "painful" alternative way for biomedical technological innovation - special specifications or special purpose, and not new technology or first of a kind. In contrast, the calibre of product or personnel is a passive descriptive concept, which does not imply a specific technolo-

gical innovation strategy.

The impact of the FDA regulations

Before we address our second hypothesis, dealing with the causal relations between technology, risk associated with product use, and the impact of the FDA regulations, it is important to understand the various dimensions of the FDA requirements which bear upon the biomedical firm.

Sixty five percent of the products of the firms in our sample were regulated by the Bureau of Medical Devices of the FDA and 27% by either the Bureau of Drugs or Biologicals. Only two firms considered themselves not regulated at all, either because they had launched their products (medical devices or auxiliary products) before those categories were included in the FDA regulations, or because their products were quite removed from the clinical and consequently the regulated core of the industry.

The entrepreneurs reported that the FDA regulations influenced their product strategies on the average 3.2 points on a 5-point scale (64%), and their impact on the firm in general, as measured by the number of operational issues impacted by the regulations, 2.8 points on a similar 5-point scale (56%). Forty two percent reported that the regulations were prone to inconsistent interpretations of the FDA examiners, and 19% claimed that their products had actually been misclassified by these examiners into wrong categories, probably due to insufficient FDA professional understanding.

The medical devices and auxiliary products in our sample were mostly of FDA classes I and II (86%), which require nonclinical proof of safety and efficacy, while 14% were of class III, requiring

clinical tests. The former products were usually approved in the frame of paragraph 510K of the 1976 amendment, which is known in the industrial jargon as the "510K form". Those firms had to wait on the average between 45 and 90 days for "approval from Washington", though for most of the firms (62%) the process did not take more than 45 days. The approval process for class I and II products usually did not require more than one additional iteration, initiated usually by the FDA examiners due to some missing data, product misclassification or simply lost correspondence.

The climate for pharmaceutical and biological products is much more restrictive. Approval of an investigational new drug (IND) application for preliminary tests of efficacy takes between two and five years. The premarketing approval of a new drug application (NDA) has been of similar magnitude, resulting together with the IND in 6 to 10 years of iterative testing and application.

The sampled firms' reported out-of-pocket expenses for external consultants, costs of clinical tests, special facilities or labeling procedures and other similar costs, range from none to $120,000 per annum, with a $30,000 median. We assume that neither figure includes lost revenues caused by the delays, nor the time spent by the founders.

It is interesting to know whether the intervention by the federal authorities has been warranted by real issues of safety and efficacy of the products. Although our data do not address the cost-benefit analysis of government regulations, we tested whether products which were evaluated by the experts panel as having high RAWU drew more "fire" from the FDA . The data presented in Table 3 support the overall validity of at least the direction if not the intensity

Table 3 approximately here

of the FDA intervention. The correlations between RAWU and the impact of the FDA regulations on the firm, especially as measured by the overall RAWU of its products, are statistically significant. It seems logical that the impact of first product's RAWU was the most significant: launching a product of high risk associated with its use can be a quite critical event for a young firm. The increasing correlations between the FDA-precipitated expenses and the RAWU of products 2 and 3 is more difficult to explain. We hypothesize that most of the FDA expenses related to the first product were perceived by the interviewed entrepreneurs as founding expenses, while the expenses related to the second and third products were perceived as operational, and were reported as such.

The Financial Threshold Effect

The general financial attributes of biomedical firms are comparable to other technology-based enterprises (Table 4). For instance, Taylor (1981) reported an average of $67,000 in initial equity and $48,000 in loans, totaling $115,000 in initial capital of his industrial "spin-off" firms that were founded between 1960 and 1981. In our sample the co-founders and their families provided approximately 62% of initial capital base, with venture capitalists and banks playing quite a minor role at this initial stage. The subsequent resource mobilization was more substantial, with an average

of more than a million dollars in long-term capital, accompanied of course by gradual shifting of equity control of the firm away from its initial founders. External ownership increased from 10% to 23% on the average from founding till 1983, with at least five firms having been acquired by larger biomedical firms or by conglomerates.

Table 4 approximately here

At this stage of analysis the presence of financial outliers in the sample must be treated. Two firms, which incidentally have both recently been acquired, had extensive capital financing. These two firms succeeded in mobilizing $850,000 and a million dollars in initial financing, and their later public offerings generated additional $9.2 and $6.4 million dollars in equity, respectively. Their economic performances have been accordingly outstanding, with $30 and $9 million sales in 1983, averaging $24.4 and $7.2 million in annual sales between 1980 and 1983, respectively. In comparison, the total sample's annual sales mean (Table 5) for the same period was about $2.5 million (for the 22 enterprises which still independently existed in 1983). These 22 firms generated $55 million in sales in 1983, and about 1100 in employment, with the two outliers contributing approximately 60% to these figures. This concentration of success is not unlike the relative role of Digital Equipment Corporation (DEC) among the 50 firms that had emerged from MIT's Lincoln Laboratory (see Roberts, 1968).

Table 5 approximately here

This information is useful for statistical testing of the causal relation between a firm's financial inputs and its economic performance. Clearly the presence of outliers distorts this relation: the positive Pearson's correlation between the total initial capital and average sales between 1980 and 1983 of R=0.49, decreases to statistically insignificant R=0.10 when the outliers are excluded.

The second hypothesized determinant of a firm's economic performance is its technological innovativeness, as measured by the technological sophistication of the firm's products. We found that the associations between the indicators of technological innovativeness of the firm's products and its average annual sales are somewhat ambiguous (Table 6): first, the start-up period presents an unstable pattern, with correlations ranging from -0.16 to 0.32 for the first three products of the firm, with R=-0.02 for the products' average. Second, although the correlations between the technological indicators and the annual sales between 1980-1983 are positive, they are still not significant statistically.

Table 6 approximately here

In accord with our previous findings it was essential to test

these relations for the influence of the two financial- performance outliers. The results of this procedure are quite eloquent (Table 7): the ambiguous positive relations between the indicators of technological innovativeness and economic success become explicitly and significantly negative for the 20 firms which could not mobilize the necessary "threshold" financing attained by the two performance outliers.

Table 7 approximately here

The concept of minimal "threshold" financing, below which the net contribution of technological innovation to economic success becomes highly dubious, gains some support from our previous findings on the impact of the restrictive policies of the FDA. We should bear in mind that FDA policy has been especially critical to those firms which attempted to develop and market technologically novel products. Putting it differently, unless the biomedical firm is adequately financed at founding (which in this sample from the 1970-1975 context meant between $850,000-1,000,000), its technological innovativeness will be detrimental to its economic performance. The mediating role of the risk associated with the use of firm's products, and the problems posed by the FDA "quality assurance" procedure, seem quite plausibly to be a severe externally imposed handicap on technologically innovative firms.

The final step of causal analysis brings together the main potential determinants of economic success of biomedical enterprises -

the technological and the financial inputs, and the risk associated with product use (RAWU), which negatively mediates between technological innovation and economic performance. The variables are selected to facilitate causal inferences; the causal relation between mobilization of resources and economic performance might conceivably be reversed because initial economic performance might increase a firm's credibility, which can generate positive speculations about its future, facilitating the mobilization of substantial external capital through public or private offerings. In contrast with this possibility, the initial capital explicitly precedes in time the 1980-1983 sales, consequently controlling for reversed causality. Second, both the technological innovation and the RAWU measures are based on products which had been launched mainly between 1970 and 1979, with only 29% of them entering the market between 1980 and 1983

Table 8 approximately here

(Table 8). The sequence of these events in time is graphically described in Figure 2. The formation of the products' attributes mostly took place

Figure 2 approximately here

in the mid-seventies and consequently cannot be the outcome of economic performance of the firm between 1980 and 1983.

The results of the regression analysis are indicative of the same process, already elicited through the bivariate inferential analysis. It seems from the regression that initial financing becomes quite inconsequentially related to economic performance of an average biomedical firm. On the other hand, the independent effect of technological innovation on the firm's success is negative and statistically significant; the role of the mediating RAWU is negative, though clearly not significant.

Table 9 approximately here

This analysis suggests that significant technological innovation in biomedical area should be undertaken only by those young firms which succeed in securing not less than some significant threshold level (here $850,000 to a million dollars) as initial founding capital. Otherwise the requirements of the product evaluation procedure, enforced by the FDA, will render these attempts at technological innovation economically counterproductive. Alternatively, young and potentially innovative biomedical firms might seek to couple with the financial reources of larger corporations in strategic alliances aimed at achieving mutual benefits.

Managerial Implications

This study contributes to further understanding of a uniquely important feature of the medical field - that technical innovation is a double-edged sword, unlike in the other areas of technology. Greater

innovation in the biomedical area generally brings with it higher risk associated with use of the medical products. In turn FDA regulatory impact directly correlates with the extent of assessed innovation. The implication is that unless the young company is particularly well financed, the effect of FDA regulation is to prevent the innovative firm from experiencing economic success in the marketplace.

The empirically revealed division in the sample of young biomedical firms - that underfinanced companies languish when they innovate and well-financed innovative companies succeed - provides an interesting basis for possible ties between large and small companies in the biomedical industry. Large and small companies have potentially significant mutual benefits to gain from linkages such as sponsored research and/or product development, venture capital investments by the large in the small, and especially by creation and nurturing of on-going strategic business alliances, perhaps including formal joint ventures. This research has explicated the lack of adequate capitalization of most innovative young biomedical companies, while it has also evidenced their lack of experience with the FDA, and their lack of appropriate and strong marketing channels. Larger medical products firms have already managed to overcome these cited dimensions of deficiency. But the young firms bring high levels of entrepreneurial commitment and demonstrated high levels of technological innovation, achievements that may be less attainable in the larger corporation. Opportunities for complementary co-relationships seem abundant.

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Table 1: Attrition of the initial sample during selection and data collection

Year of incorporation	Total	1970	1971	1972	1973	1974	1975
Initial sample	506	65	76	66	92	78	129
Stage 2 selection	106	13	19	20	13	9	32
Mailing list of questionnaires	36	5	5	7	4	6	9
Complete data collected	29	5	5	7	2	5	5

Note: A 1974 incorporated firm had actually been founded in 1968, and a 1975 incorporation had been started in 1969.

Table 2: RAWU and the technological dimensions of the firm

Technological dimensions of firm's products	Risk associated with use of: First product N 26	Second product 20	Third product 16
New technology or first of kind	0.34**	0.45**	0.33*
Special specifications or special purpose	0.06	0.09	0.06
Calibre of product or personnel	-0.14	0.10	-0.18

Pearson correlations: *p=0.10; **p=0.05. Positive correlations indicate association of high RAWU and high score on the technological dimensions.

Table 3: Impact of the FDA regulations and the risk associated with use of firm's products

Risk associated with use of firm's products	Overall impact of FDA regulations		Expenses for the FDA interface	
	N	R	N	R
First product	26	0.35**	19	0.20
Second product	19	0.29	15	0.32
Third product	16	0.14	13	0.51**
The firm (products average)	26	0.32*	19	0.47**

Spearman and Pearson correlations: *p=0.10; **p=0.05. Seven entrepreneurs could not evaluate their FDA interface expenses.

Table 4: Financial profile of biomedical enterprises

Financial parameters of the firm	(N)	Range Minimum ($ 000)	Range Maximum ($ 000)	Average ($ 000)
Initial equity	(25)	0	850	75
Initial loans	(25)	0	450	56
Total initial capital	(25)	1	1,000	130
Subsequent long-term capital	(24)	0	9,200	1,064*

*Excluding the firms that were dissolved, it averages $1161K.

Table 5: Industrial and economic profile of biomedical firms

Industrial and economic parameters	(N)	Range Minimum	Range Maximum	Average for all firms
Founding - first 2 years	(26)			
Average annual sales ($000)		0	918	158
Number of employees		0	37	6
Proportion of exports(%)		0	10	1
1980 - 1983	(22)			
Average annual sales ($000)		0	24,410	2,490
Number of employees		1	483	50
Proportion of exports(%)		0	30	6

Table 6: Technological innovation and economic performance of the firm

Technological Sophistication Indicators for	(N)	Economic Performance: Annual Sales First 2 years	Annual Sales 1980-83	Estimated Market Value 1977	1980	1983
First product	(26)	-0.16	0.18	0.29*	0.26	0.25
Second product	(20)	0.28	0.19	0.30*	0.30*	0.24
Third product	(16)	0.32	0.27	0.35**	0.37*	0.30
The firm (products' average)	(26)	-0.02	0.14	0.31*	0.27*	0.24

Pearson correlation: * p=0.10; ** p=0.05.

Table 7: Technological innovativeness and economic performance

Technological innovativeness of firm's products	Average annual sales 1980-83 Excluding	
	Dissolved (N=22)	Dissolved and outliers (N=20)
New technology or first of kind	0.17	-0.47**
Special specifications or purpose	0.06	-0.44**
Calibre of product or personnel	-0.01	-0.60***

Pearson correlations: *p=0.10; **p=0.05; ***p=0.01.

Table 8: Schedule of launching new products by biomedical firms in the sample

Year of market entry	First product		Second product		Third product		Total products	
	%	N	%	N	%	N	%	N
1970-1974	68	17	40	8	25	4	47	29
1975-1979	20	6	30	6	19	3	24	15
1980-1983	12	3	30	6	56	9	29	18
Total	100	26	100	20	100	16	100	62

Figure 1: The biomedical research spectrum (Roberts et al., 1981: 7)

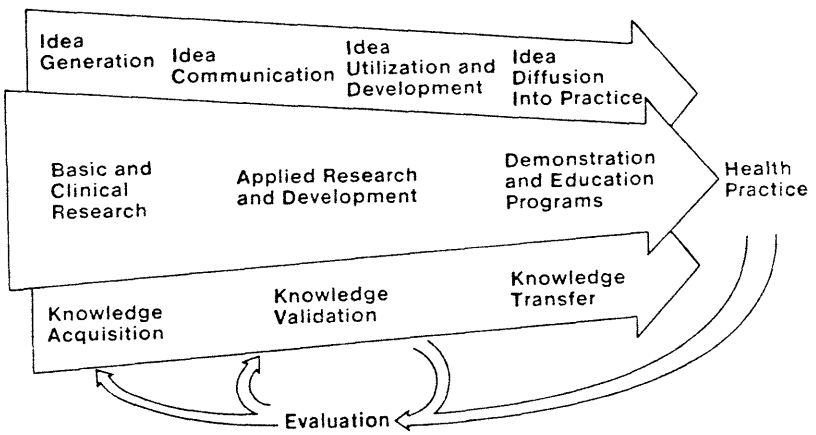
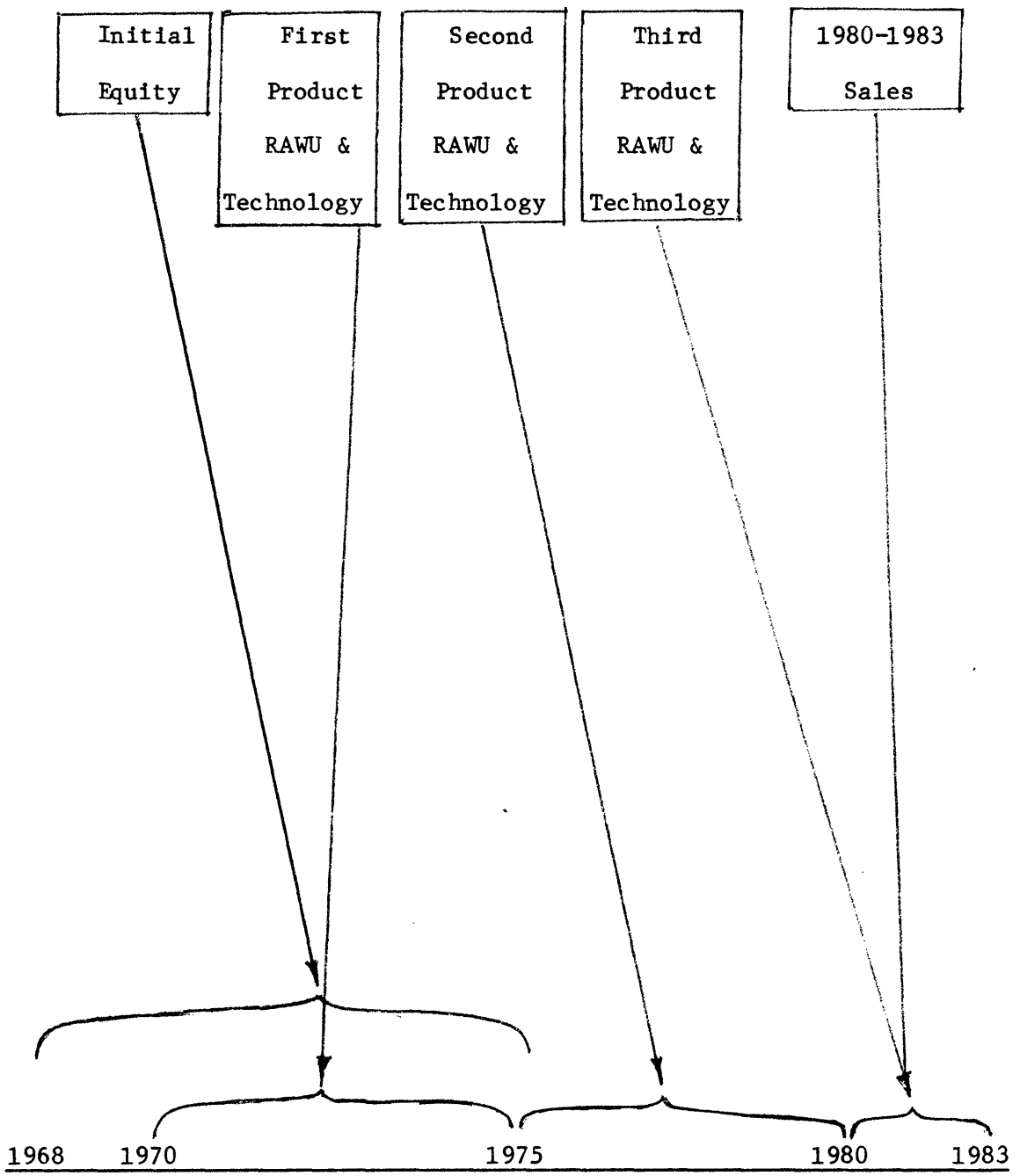


Table 9: Multivariate regression: determinants of economic performance of biomedical firms

Dependent variables	Average annual sales 1980 - 1983			
	E x c l u d i n g			
Independent variables	Dissolved		Dissolved and Outliers	
	BETA	F	BETA	F
Initial capital	0.60	6.3	0.10	0.2
Technological innovativeness of the firm	-0.15	0.5	-0.60	7.7
Risk associated with use of firm's products	-0.15	0.5	-0.12	0.3
R square	0.28		0.36	
F	2.18		2.75	

Figure 2: The time sequence of the variables in the causal model of economic performance of biomedical firms



Appendix A: Sample attrition statistics (after stage 2)

Cause for Attrition	Total N	Year of Incorporation 1970	1971	1972	1973	1974	1975
Total set after selection stage 2	106	13	19	20	13	9	32
1. Dental clinic	2						2
2. Not medical	2				2		
3. Only marketing	3				1		2
4. Actually incorporated too early	5	2	2	1			
5. Not originally incorporated in Massachusetts	1						1
6. Do not want to talk	16	2	3	2	2	1	6
7. No address or contact	47	4	9	10	6	3	15
8. Founder dead	2			1			1
9. Inadequate data	2	1	1				
Total attrition	80	9	15	14	11	4	27
The final sample	26	4	4	6	2	5	5

Appendix B: Sample descriptive data

B-1: Business classification

Business Definition	Frequency 1968-1975 N	%	1980-1983 N	%
Marketing only	2	8	-	-
Manufacturing only	3	12	3	12
R&D and consulting	4	15	-	-
R&D and manufacturing	6	23	6	23
From R&D to marketing	11	42	17	65
Total	26	100	26	100

B-2: Product area

Product Area	Frequency N	%	N	%
Auxiliary products	6	23	6	23
Medical devices	10	38		
Medical devices and auxiliary products	4	15	14	53
Drugs/pharmaceuticals	3	12		
Drugs/pharmaceuticals and auxiliary products	2	8		
Drugs/pharmaceuticals and medical devices	1	4	6	24
Total	26	100	26	100

Appendix C: Descriptive statistics of RAWU

D-1: Distribution statistics of RAWU raw scores

	First Product		Second Product		Third Product	
N	26		20		16	
Statistics	PAT(*)	INV(*)	PAT	INV	PAT	INV
Mean	13.4	14.7	12.8	14.2	14.7	15.1
Median	13.8	16.0	10.5	16.0	14.5	18.0
Std. Dev.	5.5	5.9	6.2	6.4	5.6	6.6
Skewness	-0.3	-0.6	0.1	-0.4	-0.6	-0.8

* PAT = RAWU to the patient; INV = Invasiveness.

D-2: Distribution statistics of RAWU by products, and firm's average

	First Product	Second Product	Third Product	Firm
Statistics N	26	20	16	20
Mean	28.2	27.0	29.8	27.9
Median	28.5	28.5	32.5	28.1
Std. Dev.	11.0	12.3	12.1	10.1
Skewness	-0.5	-0.2	-0.7	-0.4