THE PROCESS OF TECHNOLOGY TRANSFER TO THE NEW BIOMEDICAL AND PHARMACEUTICAL FIRM

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Abstract

This paper applies the theories of technological innovation to the process of technology transfer to biomedical and pharmaceutical start-ups. It is based on detailed data gathered from 26 firms, founded between 1968 and 1975 in the Commonwealth of Massachusetts.

The routes of technology transfer were traced, and the comparative impact of entrepreneurial professional experience, and the continuous flow of information to the firm were evaluated. In this context, the dominant role of the hospital and the medical school were elicited. Even weak contacts with universities and hospitals were found conducive to transferring technology from research to industry, enhancing technological innovativeness of the young biomedical firm. On the other hand the relation between technological attributes and economic success of the biomedical firm is more complex: a)contacts with the clinical environment do not significantly facilitate its economic performance; b)technological sophistication and advancedness of firm's products are not dominant factors in determining its economic success.

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Introduction: Transferability of Non-biomedical Research

The theories of technological innovation are not industry or technology specific, with only slight differentiation being made in the literature between technology-based industries such as semiconductors, computers, biotechnology, biomedical and pharmaceutical products, scientific and engineering instruments, and special manufacturing processes and materials, versus such basic industries as steel, textile, food, chemical industries, and agriculture.

The estimated volume of the U.S. biomedical and the pharmaceutical industry is quite significant, approximately 25 billion dollars in 1980 (Gibson et al., 1983; Frost and Sullivan, 1983). Despite this size, most of the research on technological innovation focuses on the non-biomedical industries. For instance Von Hippel (1977) studied the sources of innovation in the semiconductor and electronic subassembly processes, Freeman (1965) analyzed the R&D process in the electronic capital goods industry, and Tilton (1971) and Golding (as cited in Tilton, 1971) concentrated on the diffusion of technologies by using semiconductor technology as a case in point. Roberts (1968) studied the "spin-off" of new firms from MIT academic departments and laboratories, as well as government and industrial organizations. Knight (as cited by Von Hippel, 1982) used the data from the computer industry between 1944 and 1962 to describe the process of technological development. Research on innovations in scientific instruments (Von Hippel, 1977) and clinical chemistry analyzers (Von Hippel & Finkelstein, 1979) was more relevant to the biomedical industry, but it still did not address issues specific to it. More recently Horwitch (1982) presented biotechnology as a case in

point of a field with high technological complexity.

On the other hand most of the studies of the biomedical industry are not based on theories of technological innovation. Coleman, Katz and Menzel (1966), and recently Leonard-Barton (1983) studied the diffusion of innovations as a two-stage communication process. The studies of Ashford, Butler and Zolt (1977), Young (1982) and Wardell (as cited in Roberts, 1981) focused on the pharmaceutical industry and the influence of the Food and Drug Administration (FDA) on the industry's productivity and innovativeness. Another cluster of relevant research focused on the changes in the pharmaceutical industry, historically analyzing the interaction between technology and the regulatory environment (Temin, 1979; Fuchs, 1974; Measday, 1977). They also address the economics of this industry. The analysis of medical innovations by Bernstein, Beaven, Kimberly, and Moch (1975, 79-114) focused solely on diffusion-relevant attributes of medical technology.

Only a few studies address the complex issues of technological innovation in the biomedical industry. Comroe and Dripps (1977) rigorously analyzed the relation between basic research and its application in two areas of medicine. The Committee on Technology and Health Care of the National Academy of Science (1979) provided rich conceptual background for the analysis of equipment-embodied technologies but still insufficient empirical data. In recent work Finkelstein and Homer (1984) used system dynamics to model the decision-making process of FDA policy makers in regulating emerging technologies.

The theories of technological innovation have not yet been tested extensively with empirical data from the biomedical industry.

But if this industry does not differ substantially from such industries as semiconductors or electronic instruments, we might assume that the theory will be still applicable to this context. Moskowitz, Finkelstein, Levy, Roberts and Sondik (1981) caution: "In understanding the stages of technological development in health, we can best benefit from previous research in other fields by carefully examining health-related patterns rather than quickly accepting the applicability of these findings to the health field" [our emphasis] (p.6).

The question of transferability becomes more acute in the face of some significant idiosyncracies of the biomedical industry (Moskowitz et al., 1981: 6-7). First, the industry is heavily regulated by the federal government, especially by the FDA. 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.

Second, the industry is supplying its products and technologies in a complex industrial goods market (Roberts, 1981), in which medical practitioners serve as intermediaries between producers and ultimate users - the patients. It should be noted that in this industry, relative to others, many practitioners have closer relationships with researchers because they have the opportunity to interact in their natural work environment - the hospital. This is especially true for those practitioners who are associated with academic medical center "teaching hospitals".

Third, the biomedical industry is an all-encompassing name for a wide variety of products, embodying such scientific and engineering disciplines as biology, anatomy, microbiology, physiology, electronic and mechanical engineering, material and computer sciences, and many others. The various configurations of these disciplines present a wide range of proximity to the clinical "core" of the industry. It is not clear what proportion of so-called biomedical firms produce diagnostic or therapeutic products of significance for the patient. How "medical" are these products, and to what extent are the idiosyncracies described above typical of them?

The best that can be done is to combine "...empiricism largely from nonbiomedical fields with speculations on the transferability of ideas to the biomedical area" (Roberts, 1981: 51). The conceptual model presented by Moskowitz et al. (1981, 3-5) sets a structured research agenda for the biomedical field. This model (Figure 1) consists of two distinct processes - the progression of technology from ideas to products and practices, and the interactions among people which facilitates this flow.

Figure 1 approximately here

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, in addition to being interesting for the understanding of formation of new enterprises, also represents the junction of these processes. As a

research locus the small firm should also contain sufficient data about most of the sources which influence innovations listed by Roberts (1981), such as staffing, idea generation and exploitation, and structural and strategic issues.

Research Questions and Hypotheses

The transfer of technology to the firm is a well-articulated area of the theory of technological innovation. The perspectives relevant to the analysis of the biomedical industry include the informational links between basic research and industrial research and development. These were established by Comroe and Dripps (1977) to be vital in some instances for the biomedical industry. Allen (1977) presented specific findings concerning the patterns of communication of scientists and engineers.

Mobility of personnel was found to be one of the most effective routes of technology transfer, both in the national and the international domains (Allen, Hyman, & Pinckney, 1983). The studies of "spin-offs" by Roberts (1968) and Taylor (1981) address the same issues, having found that the intensity of technology transfer from the previous employer of the founders to the newly founded firm has been conducive to its commercial success.

A different question is whether technological advancement of the firm and its products contribute to commercial success. Several studies (e.g., Marquis & Meyers, 1969; Rothwell et al., 1974) found that valid understanding of customers' needs, and product ideas that were generated from market inputs led to better economic performance at the product level than "technology-push" products. The importance of users as sources of product ideas as documented by Von Hippel

(1977, 1982), contains direct implications for the potential role of the hospital in the biomedical industry.

The research questions that we address in this study stem directly from the existing knowledge and understanding of the processes of technological innovation: a) How important is the mobility of personnel from hospital and university research, from large biomedical firms, and from other technology-based or basic industries, for technology transfer to the new biomedical firm? b) How important is the hospital as the source of both product ideas and technologies, and of need data, for the small newly founded firm? c) How important is technology transfer to the biomedical firm to its commercial success?

These questions can be formalized into specific hypotheses, based on the presumption that findings of the theory of technological innovation are indeed transferable to the biomedical industry. The following hypotheses address these issues:

H1: The relevance and advancedness of the professional background of the founders influence the technological sophistication of a firm's products.

H2: The relevance and advancedness of product ideas and the technology transferred to the firm enhance the technological sophistication of a firm's products.

H3: Contacts with hospitals are conducive both to technological sophistication of a firm's products and to commercial success of the firm.

H4: High technological sophistication of a firm's products does not necessarily result in its high economic performance.

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 consisted of six stages:

1. Corporations whose names suggested either a medical, pharma-

ceutical, biological, or a general technical context were selected from the 1970 to 1975 Massachusetts State House incorporation records. Those firms which either did not have the required vertical integration, were previously incorporated outside of Massachusetts, or (despite their names) 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. This stage reduced the population from 506 to 106 firms.

2. To extent possible the founders of the remaining firms were located. It should be noted that firms that had been dissolved were not eliminated from the sample, though they were extremely difficult to trace. Inability to locate founders or firm resulted in over half of the drop-outs from the sample at this stage. Experience with prior studies of entrepreneurs suggests that most of these drop-out firms had never really been activated, despite incorporation.

3. A structured interview was tested with four firms chosen from the target population, the questionnaire modified from earlier work 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. Following initial testing the research instruments were finalized, consisting of a self-administered questionnaire that contained mainly well-structured and simple questions, and an interview questionnaire, containing unstructured or complicated issues which required real-time clarifications or explanations.

4. Efforts were undertaken to enlist the founders' agreements to participate. 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".

These obstacles produced difficulties in obtaining information about the comparative performance or the product area of the firms which dropped out of the sample at this stage. As far as we can tell attrition biases are not significant. It is possible that the attrition of firms which were dissolved, or encountered severe operational difficulties, was comparatively high. At least one firm was under FDA investigation and was advised not to 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.

5. The self-administered questionnaire was mailed to 32 founders of biomedical firms (excluding the pilot study), resulting in another 7 drop-outs 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 negotiation to Europe till the end of March".

There are no specific patterns of sample attrition at this stage, although again our data about the comparative economic success of drop-outs is incomplete. Of the drop-outs at least one 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.

6. 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.

Three additional 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.

The bias introduced by the various non-respondents appears mainly to be under-representation of the firms which were either dissolved, acquired by large conglomerates, or relocated to other regions of the U.S. For instance one non-participating firm had been undergoing acquisition by a Texas corporation, another was under federal investigation by the FDA, two relocated to Florida and California, and two founders just recently died (see summary of sample attrition in Appendix A).

On the other hand, the firms included in the sample appear to

be 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 the scores on the scales of the importance of a)new technology or first of kind, b)special purpose or special specifications, and c)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; for detailed data see references on footnote next page.)

Another method of aggregation was used to derive the overall product specific technological index. Product specific scores on the above three scales, considered as indicative of technological

sophistication or advancedness (alphas ranged between 0.50 and 0.60), were summed, becoming the index of overall technological sophistication of the firm which was found to be highly reliable (alpha=0.70).

Technological attributes of founders' background

The technological attributes of founders' professional background and experience were ordinally scaled on technological sophistication and relevance. Entrepreneurs who held predominantly R&D or research positions were encoded as "high" on technological sophistication of their professional background, and all the others were encoded as "low" (see Appendix C-1 for relevant examples).

Entrepreneurs whose previous employment was predominantly in universities or hospitals were encoded as "high" on relevance and technological sophistication of their industrial background, those with medical or pharmaceutical industrial experience were encoded as "moderate", and the rest as "low" (see Appendix C-2 for relevant examples).

Technological sophistication of the sources of technology

The sources of product technologies and ideas were ordinally scaled on technological sophistication and relevance. Product technologies which came predominantly from universities and hospitals

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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.

were encoded as "high" on relevance and technological sophistication, those mostly from the public domain were encoded as "low", and the rest as "moderate" (see Appendix C-3 for relevant examples).

Product ideas predominantly from universities, inventions, or from research consultants were encoded as "high" on relevance and technological sophistication. Refinements of existing products or evolution from past work were usually encoded as "low", with the necessary correction for entrepreneur's professional and educational background, and the rest as "moderate" (see Appendix C-4 for relevant examples).

Results

Technology Transfer to the Small Biomedical Firm

Technology tranfer to the small firm takes place mainly in two forms: first, through personnel mobility, which carries the technological knowhow accumulated by the founders with their previous employers, during their education, and through their general experience. It can be described as a "spin-off" process, although in previous studies by Roberts and associates they used this term more specifically to describe transfer of technology from established technology-based organizations to new high-tech start-ups.

The second source of technology is the continuous flow of information from the firm's environment through both formal and informal channels, such as literature, personal contacts, professional conferences, vendors, users and suppliers. This area has been extensively researched and documented by Allen and associates. A comprehensive summary of relevant data is presented in Allen, Hyman and Pinckney, Table 7 (1983: 203).

Taylor (1981) showed that the knowhow gained at the previous employer of the founder was essential for the founding of the new firm. In our study 50% of the respondents indicated that their firm could not have been started without this technology; an additional 13% indicated that an important aspect of the company's work originated at the previous employer (48% and 17%, respectively, in Taylor, 1981).

When we tried to trace the influence of the entrepreneur's background on the technological sophistication of firm's products, the following three components emerged as the most salient:

1. The technological sophistication of the entrepreneur's professional background;

2. The relevance and the technological sophistication of entrepreneur's industrial background; and

3. The importance of the technology transferred to the firm for its establishment and operations. This variable actually represents the intensity of the link between the technology of the "parent" firm or firms and the new enterprise.

It is reasonable to assume that the background of the founder is only one of the factors which contribute to the technology of the firm. The relations between the background of the founder and the technological attributes of the firm's products are all in the expected direction, although not statistically significant (Table 2).

Table 2 approximately here

However, the intensity of technology transfer, measured on an ordinal

scale proved to be correlated positively and significant statistically with two of the technological attributes of firm's products: a)embodying a new technology or being first-of-kind ($p \leq 0.08$), and b)the perceived calibre of the product or of firm's personnel ($p \leq 0.06$).

Another related question is to what extent the technology transfer achieved through participation of MDs influences the firm's technological attributes.

According to the results presented in Table 3, the participation of MDs in founding new firms works in the direction of facilitating technological innovation in the firm: its products tend to incorporate newer technologies, and have special specifications, but these relations again are only of marginal statistical significance.

Table 3 approximately here

An aggregate index of initial "spin-off" technology transfer was derived by multiplying the three above components. The index correlated with the technological sophistication of the firm with statistical significance: Pearson $R=0.49$ ($N=26, p \leq 0.008$). The

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Statistical footnote: A brief explanation of the statistical data presented in Table 2 is in order. It is typical of the hypothesis testing procedure when we are looking for associations between an ordinal and a nominal variable. This situation renders the t-test incorrect. Consequently, we apply non-parametric tests such as Mann-Whitney (for comparison of two samples) or Kruskal-Wallis (for comparison of k samples).

importance of the intensity of technology transfer by the "spin-off" process from the previous employer was emphasized by the fact that an alternative index which comprised only the two background variables but not the intensity of technology transfer to the firm produced a much lower correlation of R=0.13 with the technological sophistication of the firm. This regularity was also maintained for the average calibre of a firm's products or personnel: R=0.31 with the overall technology transfer index, but only R=0.09 with the background index, when the intensity of technology transfer was excluded.

Another aspect of the technology transfer process is revealed by our data concerning part-time involvement in the firm's activities by these biomedical entrepreneurs (Table 4). It seems that technologically more sophisticated products either required more preparatory time for R&D activities, or they were generated and exploited by entrepreneurs whose work environment (e.g. academic and R&D) permitted sufficient slack for their activities related to founding the new firm. In the face of our data related to the "spin-off" process of technology transfer, the latter explanation seems more plausible. Part-time involvement also indicates that the entrepreneur was continuously involved in both his "prior" job and his new firm over an extended time period.

Table 4 approximately here

The second source of a product's technological attributes is the continuous flow of product ideas and technologies to be embodied

in the final product. The data presented in Table 5 show that advanced sources of product ideas and technologies enhance technological

Table 5 approximately here

innovation in a firm's products, though again, except for their impact upon new or first-of-kind technology, the separate statistics for each of the source components are not significant. Following a procedure similar to the one applied to the indicators of the technological "spin-off" (Table 2), we derived the multiplicative index of sophistication and relevance of the continuous technological flow. This index correlated with the sophistication of firm's technology by $R=0.32$ ($N=24, p \leq 0.005$), and with the duration of part-time involvement of the founders by $R=0.36$ ($N=23, p \leq 0.05$).

For corroboration of the determinants of the continuous flow of technology to the biomedical firm we tested the importance of informal contacts with the clinical environment - hospitals and medical schools. The role of the clinical environment, hospitals and medical schools, as a source of continuous flow of technology and product ideas to the firm, cannot be exaggerated. In accord with Allen (1977), these contacts proved to be very strong determinants of the technological attributes of the firms' products. The results in Table 6 show that firms which maintained even weak contacts with the clinical environment developed products that incorporated newer technologies and/or special specifications, and were of high perceived calibre.

Table 6 approximately here

To trace the comparative importance of the two sources of technology for the technological advancement of the firm, we used path analysis for linear modelling. The BETA coefficients of the path analysis model presented in Figure 2 indicate that the two sources complement each other in transferring technology to the new firm. The regression coefficients for both sources are statistically significant, and the resulting R^2=0.32 is quite high for this type of data.

Figure 2 approximately here

The impact of the continuous flow of technology on the firm is somewhat weaker than the initial "spin-off" transfer by the founders. The fact that path modelling for the first product of the firm elicited the dominant role of the initial "spin-off" process (R^2=0.26, BETA=0.53), at the same time rendering the continuous flow of technology statistically insignificant, validates our causal inferences.

Some Implications for Economic Success

Several studies in the past used quite simple indicators of commercial success of new firms. Meyer and Roberts (1982) argued that

growth of sales "proved unreliable because it is biased towards young, fast growing firms" (p. 43). 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 at least 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 the 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 use as a single measure of firm's success.

The SAPPHO studies (Rothwell et al, 1974) point to the significance of: a)having better understanding of user needs; b)having

better external communications; and c)having early information of user problems (pp.261-267), in discriminating between success and failure of technology-based firms. We already know that contacts with the clinical environment strongly contribute to the technological sophistication of the firm's products (Table 6). A related question is to what extent do these contacts contribute to the economic performance of the firm. Our results (Table 7) for the biomedical industry do not support the SAPPHO findings: the contacts with the clinical environment which obviously carry technological information and users' need data are not by themselves significant determinants of the firm's economic performance. In our opinion this difference might point to the idiosyncracy of the biomedical milieu dscribed above (pp.4-5). It should be noted that the SAPPHO project covers other, less regulated industries, e.g. chemical and scientific instruments.

Table 7 approximately here

On the other hand the relation between technological sophistication of a firm's products and its economic success (Table 8) is in the same direction as the SAPPHO results, although not statistically strong: technological sophistication of a firm's products might be a necessary but clearly an insufficient condition for economic success of the young biomedical firm.

Table 8 approximately here

We also showed above (Table 4) that the participation of MDs in the founding process tended to enhance technology transfer to the biomedical firm. Consistent with the data in Table 7, the impact of MDs as founders on economic success of the firm is mainly negative: according to the results presented in Table 9, MDs as entrepreneurs of new firms are associated with low performance as measured by average sales after approximately a decade of operation.

Table 9 approximately here

The implications of these results are that economic success of a biomedical firm is not determined solely by the level of its technological sophistication. Additional factors contribute to performance of a biomedical company, such as financial resources and the impact of the regulatory constraints of the FDA.

Still, the technological vitality of a technology-based firm proved to be implicitly relevant to its economic success. We found that for the firms which have not excelled economically only the initial, "spin-off" source of technology is a statistically significant (regression R^2=0.25) determinant of their technology. The obvious implication is that firms which do not maintain a continuous flow of input technology, to prevent the obsolescence of their original know-how base, cannot achieve significant economic success.

Summary

Although technology transfer to the new biomedical firm contains familiar components, such as the background of the entrepreneur and the "spin-off" effect, our data imply that the technology transfer process is quite specific in the biomedical field. First, the hospital and the medical school are important specific sources of new product ideas and advanced product-embodied technologies. Second, the lag between founding the firm and its full-fledged operations is longer in comparison to the nonbiomedical firms, especially for those biomedical firms with more advanced products. On the other hand, it seems that high technological sophistication does not by itself determine commercial success. It is possible that the impact of the FDA regulations is stronger on novel and technologically advanced products, which might reduce their source firm's economic performance.

The issues related to operation of technology-based start-ups in a regulated environment is of relevance and interest to the study of biomedical and pharmaceutical firms. An article addressing these isssues is in preparation by the authors.

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

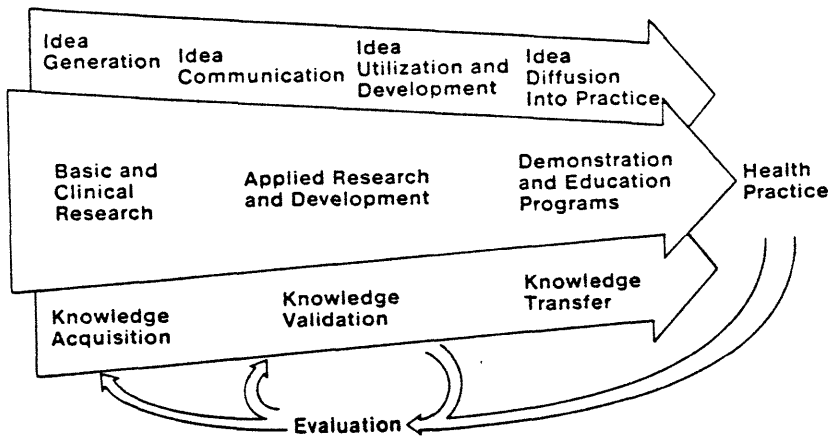

Figure 2: Path model of technology transfer to the new firm

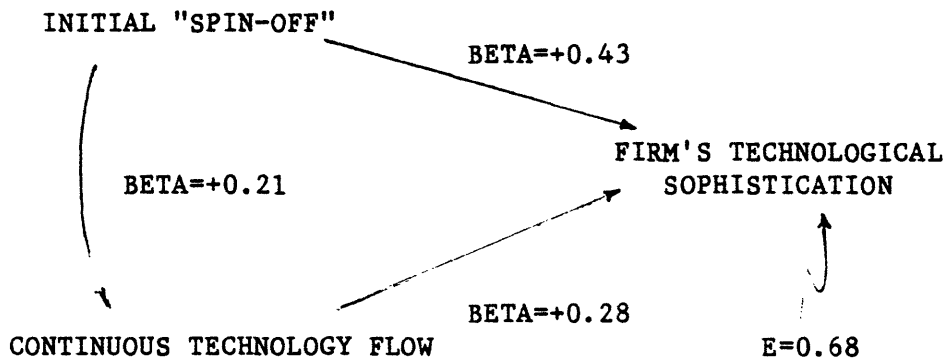

Table 1: Attrition of the initial sample during selection and data collection

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: Background of the founder and technological sophistication of the new firm

Technological attributes of the firm	Professional background: Not in R & D	Professional background: In R&D or research	Technological sophistication of industrial background: Low	Moderate	High
N	10	13	9	9	5
New technology or first of kind	11	13 (NS)	12	10	16 (NS)
Special purpose or specifications	11	13 (NS)	11	10	17*
Calibre of product or personnel	14	11 (NS)	10	12	16 (NS)

* Mann-Whitney and Kruskal-Wallis tests: $p \leq 0.10$. The table figures are mean ranks sums; higher mean ranks indicate higher average score on a technological attribute of the firm.

Table 3 : MDs as founders of new firms: their impact on firm's technology

MDs as founders	N	Product Attributes: New technology/first of kind	Special purpose or specs	Calibre of product or personnel
No MDs	19	13	13	14
At least one MD as founder	5	17	17	13
Z-scores		-1.1	-1.3	0.1
Mann-Whitney one-tail p		NS	0.1	NS

Table figures are mean ranks sums; positive Z-scores indicate higher mean ranks sum for firms with no MDs among their founders.

Table 4: Correlation between part-time involvement in founding the firm and its technological dimensions

Technological dimensions of the firm	N	Duration of part-time involvement in founding the firm
Technological sophistication of:		
First product	26	0.50**
Second product	20	0.23
Third product	16	0.13
The firm (products average)	26	0.54**
Entrepreneur's background	23	0.42*
Technology "spin-off"	21	0.49*

Table figures are Pearson correlations; *$p \leq 0.05$; **$p \leq 0.005$

Table 5: Sources of product ideas and technology, and the technological sophistication of the new firm

Technological attributes of the firms		Technological sophistication and relevance of product ideas			Technological sophistication and relevance of product technologies		
	N	Low 10	Moderate 9	High 7	Low 15	Moderate 5	High 6
New technology or first of kind		14	5	19*	9	15	9*
Special purpose or specifications		13	13	15(NS)	12	12	17(NS)
Calibre of product or personnel		13	9	18(NS)	12	12	17(NS)

Kruskal-Wallis test: $^{*}p \leq 0.01$. The table figures are mean ranks.

Table 6: The impact of contacts with the clinical environment on firm's technology

The number of clinical contacts	N	Product Attributes: New technology or first of kind	Special purpose or special specifications	Calibre of product or personnel
No clinical contacts	7	9	9	12
At least 1 clinical contact	19	15	15	14
Z-scores		2.0	1.8	1.6
Mann-Whitney one-tail p		0.02	0.03	0.05

The table figures are mean ranks sums. Positive Z-scores indicate a higher mean ranks sum for firms with at least one clinical contact.

Table 7: The impact of contacts with the clinical environment on firm's performance

The number of clinical contacts	N	Performance Dimensions: Average sales 1980-83	Market value 1983
No clinical contacts	7	11	11
At least one clinical contact	19	14	14
Z-scores		0.8	0.8
Mann-Whitney one-tail p		NS	NS

The table figures are mean ranks sums. Positive Z-scores indicate a higher mean ranks sum for firms with at least one clinical contact.

Table 8 : Technological innovation andeconomic performance of the firm

Technological Sophistication Indicators for	N	Economic Performance: Average annual sales 1980-1983	Economic Performance: Estimated market value 1983
First product	26	0.18	0.25
Second product	20	0.19	0.24
Third product	16	0.27	0.30
The firm (products average	26	0.14	0.24

Table figures are Pearson correlations.

Table 9 : MDs as founders of new firms: their impact on firm's economic performance

MDs as founders	N	Performance Dimensions: Average sales 1980-83	Performance Dimensions: Market value 1983
No MDs	19	15	14
At least one MD as founder	5	8	13
Z-scores		1.7	0.1
Mann-Whitney one-tail p		0.05	NS

Table figures are mean ranks sums; positive Z-scores indicate higher mean ranks sum for firms with no MDs among their founders.

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 for 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: Criteria and examples for encoding ordinal data

C-1: Type of work, job, position

Encode as "R&D" if work, position, or job was predominantly R&D or research. Encode "Other" for other.

Examples of job histories (the first position on the list is the most recent job):

1. Quality assurance, quality assurance, R&D - encode "Other".
2. R&D, self-employed - encode "R&D".
3. R&D, management, self-employed - encode "R&D".
4. R&D, marketing - encode "R&D".

C-2: Type of industry

Encode as "High" relevance and sophistication if predominantly university or hospital. Encode "Moderate" if predominantly medical or pharmaceutical industry. Encode "Low" for other.

Examples(as above):

1.Medical/pharmaceutical industry, and three previous jobs in high-tech industry - encode "Moderate".
2. Three recent jobs in high-tech, previous job in medical/pharmaceutical industry - encode "Low".
3. Chemical industry, university, medical/pharmaceutical industry - encode "Moderate".
4. Hospital, two jobs in high-tech industry - encode "High".

C-3: Sources of product technology

Encode "High" if sources predominantly university, hospitals. Encode "Low" if public domain. Encode "Moderate" if other.

Examples:

1. Government, university/hospital, license - encode "High".
2. Personal experience, public domain - encode "Low".
3. Purchased product line, public domain - encode "Moderate".
4. Personal experience, patent ownership - encode "Moderate".

C-4: Sources of product ideas

(see above - C-3)

C-5: Complementarity of founders' skills

Encode "High" with at least three co-founders with different skills. Encode "Moderate" with at least two different skills. Encode "Low" with either business or technical skills.

Examples:

1. Arts, Sales, MBA, Engineer - encode "High".
2. MBA, Engineer - encode "Moderate".
3. MBA, Sales - encode "Low".
4. Natural Science, MBA - encode "Moderate".

Note: Subsequently was recoded only into two categories of "High" and "Low" complementarity. The former included the original "High" and "Moderate" categories.