*SUMMARY*

*This paper identifies a small set of variables which are correlated with the innovation performance of R & D programmes in the Israeli Biomedical Electronics Sector. A total of 23 R & D programmes were considered in the analysis of which 5 – representing 48.1% of the R & D performed – were successes and 18 were failures. Information on 12 other R & D programmes was also collected, but not enough time had elapsed since their inception to be able to determine their degree of success. Therefore, they were not considered in the analysis.*

*The central variables considered are Market Determinateness (an Area Characteristic) an Innovation Profile (a Program Attribute). The former refers to the new product component of innovations and the latter involves both technical efficiency and price. All successes were highly market determinate (i.e. products with standardized functions and applications) and most of them emphasized improved technical efficiency rather than reductions in price.*

*The nature of the idea leading to the R & D programme, the type of competition prevailing in the industry and the notion of product acceptance all complement the main explanation given by the two central variables.*



# performance in innovation in the israeli electronics industry: a case study of biomedical electronics instrumentation *

by

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The purpose of our project is to develop a framework for understanding performance in innovation of science-based industry. Such a framework would enable us to define optimum strategies for science-based firms and optimum patterns of government support to science-based industry. We here report some preliminary findings on a case study of the Israeli biomedical electronics sector.

The methodological approach of the report consists in uncovering the components of optimum firm strategy from the simultaneous observation of performance in innovation at the level of individual R & D programs and the actual firm strategies which led to that performance. The research is therefore a combination of both empirical and theoretical research: there is no formal-theoretical model to determine from the outset the nature of the empirical test – the empirical and theoretical aspects continuously influence each other and both are outputs of the project.

For our purpose we can distinguish two levels of firm strategy: an overall level and a program level. The overall strategic decisions** of a firm refer to its choice of areas of activity and to the extent of involvement in each of them. At the R & D program level, on the other hand, the strategic decisions refer to the characteristics of the program (the innovation profile, the degree of

* This report presents the initial results of a research project on performance in innovation in the Israeli electronics industry directed by Morris Teubal. The original proposal, entitled "Threshold R & D Levels in the Israeli Electronics Industry", was jointly prepared with Naftali Arnon. Manuel Trachtenberg has since joined the group and actively contributed to the design of the study and the writing of the report. The project is being carried out at the Falk Institute, Jerusalem, with the financial participation of the National Council for Research and Development, the Prime Minister's Office, Jerusalem.

** On the concept of strategic decision see ref. [1a].

offensiveness, etc.). The conclusions of this report refer to both types of strategic decision, although somewhat more to those related to R & D programs.

The research will be in three stages. Stage 1 is to identify the variables most significantly related to performance; stage 2 is an analysis of failure; and stage 3 deals with constraints and policy. Each stage adds a dimension of its own to the analysis of the link between performance and firm strategy. This report covers only part of stage 1 and its conclusions should therefore be regarded as preliminary. At stage 3 we shall attempt to link government policy to performance in order to arrive at some useful policy recommendations.

## RELATION TO PREVIOUS WORK

This research resembles the work of Myers and Marquis, the Centre for the Study of Industrial Innovation, and the report on Project SAPPHO, in that the unit of analysis is the individual innovation or R & D program [2–4]. It also is related to the research done by Jones [5] in that it is specific to biomedical electronics and attempts to cover as much of the industry as possible. Of these, our report most strongly resembles the report on project SAPPHO not only because of the similarity in the unit of analysis but also because it includes both successes and failures. However, while owing a great deal to SAPPHO and to Freeman's previous work [6], it is different in several respects, some of which we now mention briefly.

(1) The SAPPHO report studies 29 innovations in the chemical and instruments sector; for each innovation there is a pair composed of one successful and one failed R & D program. Our report is not based on pairs – there are cases of more than one failed R & D program corresponding to a particular innovation and in several cases there is no successful program at all.

(2) A SAPPHO pair by definition belongs to a single market or area although the technological solutions of each program of the pair and the firm characteristics may both differ. In our study the areas or markets associated with the failed programs are not necessarily related to the areas or markets of the successful ones.

(3) In SAPPHO a search is made for variables which differentiate success from failure*. These variables do not include market or area characteristics (see the section on choice of variables). In our report we search for variables which are correlated with performance, and they may include area or market characteristics*.

(4) It follows that our methodology is more appropriate than SAPPHO's for studying a country's comparative advantage in different areas or markets of science-based industry. SAPPHO's methodology is, on the other hand, more adequate than ours for analysing the relative importance for performance of other variables related to firm behaviour.

* I.e. whose level is higher (or lower) in the successful member of the pair than in the failed member, for a significant number of innovations.



## METHODOLOGY

The methodological issues of the paper refer to problems associated with the unit of analysis, the measurement of performance, and the choice of variables, each of which is discussed separately.

### *Unit of analysis*

We term our unit of analysis "R & D program". An R & D program is a process or chain of activities ranging from the formulation of the original idea for a new product or products up to the marketing of this new product throughout its lifespan. It therefore comprises: (a) inputs (e.g., R & D, market surveys); (b) output – the new product; and (c) performance – the relation between the real value of the output and the real value of the inputs. Dividing the stream of innovative activity of a particular firm into separate R & D programs is useful if it provides a better appreciation of the factors explaining overall performance. In this context, an ideal R & D program should fulfil the following conditions: (1) that it is possible to measure performance precisely; (2) that it is possible to determine its characteristics unambiguously. The first of these is guaranteed by two conditions: (1a) that the program's outputs depend on its own inputs and not on the inputs of other programs; and (1b) that the program's inputs affect only its own outputs.

In the real world it is unlikely that a division of a firm's innovative stream into ideal R & D programs can be found. Any division is bound to involve complementarity (i.e. synergy) between the resulting R & D programs; that is, there exist R & D programs whose inputs or outputs affect the performance

* For example, "rate of growth of the market" will be positively associated with performance if the proportion of successful programs, say, in the 5–10% growth range is lower than the proportion of successful programs in the 10–15% growth range.

of other R & D programs. It is particularly useful to consider two kinds of synergy, in R & D and in marketing.

The first, synergy in R & D, occurs when the technical knowledge generated in a particular R & D program represents a useful input into one or more other R & D programs. This follows from the public-good nature of information, i.e. a piece of information never gets used up no matter how many times it is used.

Synergy in marketing occurs when the value of sales or marketing costs of the products of a particular R & D program are influenced by the fact that the firm is offering and selling products of other R & D programs. This may be due to better utilization of marketing facilities or when customers have a preference for suppliers offering a wide range of products over suppliers offering a narrow range*.

The almost inevitable synergy between a firm's various R & D programs does not enable performance in any one program to be explained exclusively in terms of that program's characteristics; the characteristics of other programs also have an influence. This does not mean that it is not useful to divide a firm's innovative stream into parts for separate analysis. It only tells us that the more synergy there is the less such a procedure will contribute to our understanding of overall performance and that the practical issue is to find a set of programs with as little as possible synergy between them.

The possibilities of dividing the innovative activity of a firm into R & D programs are also limited by the level of aggregation of the available costs and benefits data. Our division was essentially determined by the files of R & D projects submitted to the Ministry of Commerce and Industry. The impossibility of distributing the R & D costs of a particular file among the various products in the file precludes our generating more R & D programs than files. However, when market or R & D synergy were sufficiently strong we defined single R & D programs from more than one file**.

### *Measurement of performance*

We distinguish between two levels of performance, success and failure. The success–failure dichotomy is intended to differentiate between R & D programs which led to commercially successful new products and those which did not. The index of commercial success is given in most cases, for lack of

* For a more complete description of synergy see [1b].

** This was done in two instances: an R & D program combining projects for successive generations of an instrument and one combining projects for an instrument and its peripherals.



more complete information, by the ratio of the real discounted value of sales to the real value of R & D costs*. Even with complete information on direct costs and benefits, there are at least two conceptual problems of measurement: synergy (in R & D and marketing) and the length of the period of observation. The latter is the reason for having a separate group of indeterminate programs.

*Synergy:* The problem is particularly difficult when the knowledge generated in a failed program has contributed significantly to a successful one. It is practically impossible to assign a shadow price to such a piece of knowledge. A related problem may arise in marketing where in order to capture a share of the market that ensures profitable operation a firm may have to launch a series of products belonging to several R & D programs. One or more of these programs may be failures in the sense that their direct profitability (obtained by comparing sales with R & D costs) is low or negative**.

*Length of the period of observation:* An R & D program is a series of activities which take place over time and the question arises at what moment of time it is justified to make an observation with the object of determining success or failure. In other terms, what are the criteria that tell whether an R & D program has been completed or what are the criteria for evaluating an uncompleted program? There is probably no unique answer: factors such as product life, time required for market penetration and acceptance, and even the firm's future plans for the program – all these would certainly influence the answer. This problem does not appear for programs suspended during development but it is very real for those whose products have been launched and whose sales show a continuous increase but for which no reasonable sales/R & D ratio has been attained at the moment of observation. Of course, it is possible to make predictions on the basis of past tendencies and so forth, but it is doubtful whether these could be combined with the data to produce a numerical indicator of success or failure†.

* Mansfield shows for a sample of chemical, electronic and mechanical innovations that about half of the costs of *launching* a new product are R & D costs [7]. The ranking of programs according to their R & D/sales ratio will coincide with their ranking according to the ratio of total cost (both at and after launch) to sales if the R & D/total cost ratio does not vary significantly from program to program.

** In an extreme case of this kind one may be compelled to consider the set of projects corresponding to the whole line of products as a single R & D program.

† The problem is particularly difficult with completely new products for which predictions of market penetration and product life are particularly uncertain. At any rate, such predictions would be based on the *results* so that it is not legitimate to include them as part of the data *input*.

*Indeterminate programs:* Of the 35 R & D programs for which information was collected, 12 were defined as indeterminate. These are programs which at the time of observation were in one of the following situations: (a) last stages of development; (b) first stages of marketing; (c) later stages of marketing, but with no possibility of determining yet whether or not the program is successful.

The interdeterminacy of performance of these programs forced us to exclude them from the main body of the analysis. Our intention is to predict their performance in the light of the conclusions obtained from this report.

*Types of failure:* There are two types of failure within the R & D programs studied: suspension before market launch and suspension after market launch. There is no clear case of an *ongoing* R & D program which reached the commerical stage being classified under failed programs*.

These categories are purely descriptive – we have not attempted in this paper to classify failed programs according to the cause of failure: technological, market, or firm. This will be done at a later stage.

### *Choice of variables*

The report identifies some variables which are correlated with the performance of R & D programs. They are a small subgroup of a larger group of variables which were initially (and in the early stages of the research) considered of possible relevance. We call the latter group the initial set of variables.

Within the initial set of variables the first distinction is between variables which are *exogenous* to the firm and those which are *endogenous*. The former are characteristics of the areas or markets in which the firm chose to operate, a consequence of its overall strategy. The latter are related to the firm's strategic decisions about R & D programs. A third class of variables consists of those of the firm's characteristics which are given in the short run but which the firm may influence in the longer run.

The initial set of variables is as follows:

EXOGENOUS (AREA) VARIABLES

1. *Market determinateness*
2. *Product acceptance*
3. *Type of competition*
4. Extent of competition
5. R & D threshold
6. Marketing threshold

* Of course many such programs were classified as indeterminate.



7. Market size
8. Rate of growth of market
9. Intensity of spectrum effects
10. Product life

ENDOGENOUS (R & D PROGRAM) VARIABLES

11. *Innovation profile: functions and price*
12. Dominant factor in undertaking the program
13. Technological uncertainty
14. Spectrum of products offered by firm
15. Degree of offensiveness
16. Synergy in R & D with other programs
17. Synergy in marketing with other programs
18. Marketing channel

FIRM VARIABLES

19. Firm size
20. Firm growth
21. Number of years in biomedical electronics
22. Previous line of activity
23. Structure of organization of biomedical electronics

OTHER VARIABLES

24. *Origin of idea*

The five variables appearing in this list in italics make up the final set of variables entering this report. Three of them are area characteristics (market determinateness, product acceptance, and type of competition) and one reflects a strategic decision at the R & D program level (innovation profile: functions and price). The remaining one, origin of idea, does not strictly belong to any of the first three groups listed. The R & D programs were classified into one of two or more empirical categories corresponding to each of the variables origin of idea, market determinateness, and innovation profile. On the other hand, information on type of competition was not gathered at the program level, and product acceptance, although not measured directly, was conceptually linked to market determinateness. The remaining variables of the initial set were not included in the analysis of this report either because of lack of information or because the significance of the information available has not yet been established.

## UNIVERSE

As we said earlier, this research deals exclusively with one field of science-based industry: biomedical electronics. Science-based industry as a whole is a relatively new and fast-growing sector in Israel: more than half the 90 firms operating in it today were founded after 1967. This is explained mainly by the recent and growing awareness of the public and private sectors that Israel should enjoy a comparative advantage in science-based industries because of the advanced state of research in Israeli academic institutions and the relative abundance of scientific and technological manpower. As a result, these industries have in recent years received strong government encouragement and financial support.

Biomedical electronics is only a small fraction of the whole sector: we have identified and gathered information on R & D programs undertaken by 9 firms*, data that cover almost all activity ever done in this field in Israel**. Our data are therefore exhaustive in the context of the case-study and consequently we do not have to resort to statistical inferences; but on the other hand, the possibility of generalizing the results of this research to the whole of science-based industries is strictly limited.

The firms reviewed have the following characteristics:

*Age:* The Israeli firms which are or were active in biomedical electronics are all recently established: out of the 9 firms, 1 was founded in 1970, 4 in 1969, 2 in 1967, 1 in 1966, and 1 in 1964.

The fact that almost all the firms studied are newcomers to the biomedical electronics field is of paramount importance in analysing their performance and imposes an additional constraint on the generality of our conclusions†.

*Size:* It is clear from table 1 that most of the firms are very small, even by Israeli standards. This has far-reaching implications for the degree of flexibility enjoyed by them and consequently for their strategy of choice of R & D programs.

*Percentage of turnover devoted to R & D:* During 1972/73, 5 of the firms devoted 10–25% of their turnover to R & D, 2 firms 30–40%, 1 firm 50%, and 1 firm 70%, the average being 30%. This is a very high figure compared with foreign firms operating in the same field, but is consistent with the fact that most of the firms are new. Indeed, there is a very strong negative

* The data were obtained from two sources, personal interviews with the firms' managers on the basis of a questionnaire specially developed for the purpose and the firms' files at the Office of the Chief Scientist, Ministry of Commerce and Industry.

** We refer only to R & D programs undertaken by commercial firms, not by nonprofit institutions.

† Correspondingly, the behaviour of these firms may, in principle, reflect conditions resembling those of infant industries.



Table 1
Size of firms: 1972/73

| Number of firms | Turnover in IL thousand | Number of employees |
|---|---|---|
| 5 | up to 2 000 | up to 70 |
| 1 | 9 000 | 90 |
| 2 | 20 000–30 000 | 360–350 |
| 1 | 100 000 | 1 600 |

Table 2
Distribution of programs by field of medicine and function

| Field of medicine | Function | | | | |
|---|---|---|---|---|---|
| | Diagnostic[a)] | Thera-peutical | Moni-toring | Lab. | Total |
| Cardiology | 1 | 3 | 4 | – | 8 |
| Pulmonary function | – | 1 | 1 | – | 2 |
| Nervous system | 2 | 3 | – | – | 5 |
| Urology | – | – | 1 | – | 1 |
| Dentistry | – | 1 | – | – | 1 |
| Nuclear medicine | 2 | – | – | – | 2 |
| Speech aids | – | 1 | – | – | 1 |
| Other | – | – | 2 | 1 | 3 |
| Total | *5* | *9* | *8* | *1* | *23* |

a) Does not include diagnostic monitoring.

Table 3
Successful and failed programs

| | Number of programs | R & D costs[a)] | |
|---|---|---|---|
| | | Thousands of 1970 IL | Per cent |
| Successful programs | 5 | 2 405 | 48.1 |
| Failed programs | 18 | 2 615 | 51.9 |
| Suspended before market launch | *10* | *1985* | *37.8* |
| Suspended after market launch | *8* | *630* | *14.1* |
| Total | 23 | 5 020 | 100.0 |

a) Nominal R & D costs converted to 1970 prices and cumulated over the period during which the program was carried out. The deflator used is the index of wages and salaries per employee in "electrical and electronic equipment" (CBS, *Statistical Abstract of Israel 1973,* No. 24, p. 439, Table XIV/9, and earlier issues of the *Abstract*). This index was used because 60–80% of R & D costs are salaries.

correlation between age of firm and percentage of turnover devoted to R & D.

*Degree of specialization:* Only 2 firms specialized exclusively in biomedical electronics; in another 4 it was a major field of activity, and in the remaining 3 biomedical electronics was only a minor field.

*R & D programs*

We gathered information about 37 R & D programs undertaken by the 9 firms up to 1974. Two of them were dropped because not enough information was available. Another 12 were classified as indeterminate and the analysis was carried out on the remaining 23. The basic information on these 23 programs is summarized in tables 2 and 3.

## ANALYSIS: ORIGIN OF IDEA

An attempt was made to classify each R & D program according as the basic idea leading to it did or did not originate in R & D. This distinction refers both to the segment of the industry in which the idea originated and to the type of perception involved. Thus ideas originating in R & D (a) originate from R & D personnel and (b) involve the perception of a technological opportunity. If the idea does not originate in R & D then (a) it originates in users, agents, salesman, or a product manager (who in well established firms lies at the interface between technology and the market); and (b) the perception refers to a *specific* need or to a combination of need and technical opportunity which cannot, conceptually or statistically, be separated from each other*.

The distribution of successes and failures among the origin-of-idea categories mentioned above may tell us something about the pattern of linkage of technology and market most conducive to success in the Israeli biomedical electronics sector, in particular, whether an optimum product-definition strategy should start with a search for technological opportunity or with a search for a market or need. More generally, it may also provide an indication

* It is worth pointing out that the idea may originate within the firm or outside it. For example program ideas originating in R & D within the firm may represent a spin-off from other R & D programs or be the result of a search for applications of a component previously developed by the firm or its manager; ideas originating in R & D but coming from outside the firm may involve outside researchers or laboratories providing a research idea, research results, or a prototype for further development and commercial exploitation.



Table 4
Success and failure of programs, by origin of idea[a)]

| | Origin of idea R & D | Other | Total |
|---|---|---|---|
| Failure | 12 | 1 | 13 |
| Success | – | 4 | 4 |
| Total | *12* | *5* | *17* |

a) Six of the programs could not be classified owing to lack of information.

of the relative importance of technological and market factors in ensuring success. At any rate it should be evident that no clear-cut conclusions can emerge from an analysis of the origin of a program idea without explicitly considering other variables more directly related to technological and market risk.

Table 4 shows the distribution of successes and failures according as the idea originated exclusively in R & D or not, and indicates that

> The proportion of failures in programs whose idea originated in R & D exceeds the proportion of failures in the other programs.

Success in product innovations within a particular sector is the result of, among other things, an adaptation of technology to market requirements which is optimum for the sector. The process may be viewed as beginning with the program idea, whose origin may determine its future development and final outcome. The empirical findings support the view that there is a need-perception component at the origin of an R & D program which has achieved an optimum link between needs and technology*. In this context, the large number of failures reflects the fact that most of the firms were either new or recent entrants to the sector. These firms have to get hold of one or more research ideas with which to begin operating. They seldom have other alternatives since these can only result from a network of market feedback which takes a relatively long time to build up**.

* The results obtained here should be viewed as complementary to the results obtained later on in our analysis of market determinateness.

** Well established firms, on the other hand, have access to program ideas originating both in R & D and elsewhere and are also in a much better position to adapt technology to market needs. Thus, even programs originating in R & D may succeed.

## ANALYSIS: MARKET DETERMINATENESS*

A central variable in our analysis of performance in innovation is the degree of market determinateness of the products of R & D programs. Market determinateness refers to the degree of specificity of the market signals received by the innovating firm and consequently to the extent to which it anticipates (instead of responding to) demand.

In order to explain the concept we introduce four types of market signal, in ascending order of specificity: (1) signals about a need; (2) signals about a product class; (3) signals about basic functions; (4) signals about product specifications**.

Suppose that a firm launches a product in a known market. The product then represents a response to signals about a need and a product class [specificity level (2)]. Whether more specific signals are also present depends on what kind of market is being considered: if the market is sufficiently mature so that the functions of the product have already been defined (standard functions), then clear signals about the functions are also present. In this case, barring an R & D project commissioned by the final user, the firm anticipates demand with respect to specifications only. If, on the other hand, the basic functions have not been standardized then no clear signals about them have been received by the firm. It therefore anticipates demand both with respect to specifications and with respect to basic functions*. Table 5 summarizes the signals received and the demand anticipation implied by the five possible categories of market determinateness of R & D programs**.

Table 5
Specificity of signals and market determinateness

| Degree of market determinateness | Type of signal (√) or type of demand anticipation (X) | | | |
|---|---|---|---|---|
| | About need (1) | About product class (2) | About basic functions (3) | About product specification (4) |
| 1. No clearly perceived need | X | X | X | X |
| 2. Clearly perceived need but product unknown | √ | X | X | X |
| 3. Product known, but basic function not completely standardized | √ | √ | X | X |
| 4. Product known and basic function standardized | √ | √ | √ | X |
| 5. Commissioned R & D program | √ | √ | √ | √ |

* This section benefited greatly from an illuminating discussion with A. Suhami at an early stage of the work.

** In this context signals are about product characteristics or needs and not market prices (or quantities).



We postulate, *ceteris paribus*, a positive link between a program's degree of market determinateness and the expected level of (a) the product's *objective capacity* to satisfy user needs; (b) *recognition* of this capacity on the part of the user; (c) his *willingness* to consider the product when a purchasing decision is to be made[+,++].

The reason for this is the negative relationship between market determinateness and the degree of uncertainty both on the part of the innovator firm and on the part of potential users. The less specific are the signals the greater the uncertainty of the innovating firm about the precise composition of user

* Let us try to clarify what are *basic functions* and what are *product specifications* in the context of biomedical electronics. For example, each one of the physiological parameters measured in a cardiovascular monitoring system (ECG, blood pressure, etc.) would represent a basic function. Product specifications on the other hand would determine the efficiency, reliability, simplicity of operation, and degree of patient safety with which the basic functions are performed. These are in part related to the data processing and display capabilities of the system. Synchronous defibrillation is a *standard* basic function in the treatment of ventricular fibrillation and other heart ailments. A fuller discussion of standard versus nonstandard basic functions in biomedical electronics follows at the end of this section.

** The proposed categories of market determinateness are to some extent arbitrary. For example, product specification may become increasingly standardized with the passage of time. If this happens another category of market determinateness between levels (4) and (5) may be warranted.

\+ The degree of market determinateness is also presumably negatively related to the variance (a)–(c).

++ In what follows we consider individual products separately and ignore for the time being possible spectrum effects on (c); i.e. the fact that a *line* of products is offered by the firm may have a positive effect on the willingness of potential users to consider an individual product when a purchasing decision is made. These effects – which may be significant when market determinateness is high – will be considered at a later stage.

needs (and the less defined these needs are), and the more difficult potential users find it to evaluate the product's objective capacity to satisfy their needs (and again the less defined these needs are). It might be useful to separate two aspects of recognition: identification of product ($b_1$) and evaluation of its concrete usefulness ($b_2$). Identification of a product simply means assigning it to a product class linked with the satisfaction of a particular need, i.e. awareness of its potential usefulness in a very general sense. The problem of identification exists when the R & D program falls in the low or medium market-determinateness categories. The second aspect, ($b_2$), concerns evaluating the concrete usefulness of the product. The user's ability to do so increases as previously undefined functions of the product gradually become standardized.

Several remarks arise in this connection*. First, (a)–(c) will be affected not only by the degree of market determinateness – which is an area characteristic – but also by other factors pertaining to both the firm and its strategy. We have selected three: (α) the efficiency of firm's market feedback (firm and strategy); (β) marketing effort (strategy); and (γ) the firm's goodwill. Each of these factors would primarily affect the corresponding variable in set (a)–(c) e.g., the more efficient the market feedback enjoyed by the firm, the greater, *ceteris paribus* the product's objective capacity to satisfy user needs. Indirectly each factor affects all three variables. Second, each variable is related to the next; thus the greater the product's objective capacity to satisfy user needs, the greater (in general, presumably, though certainly not always) recognition of capacity and willingness to consider the product**.

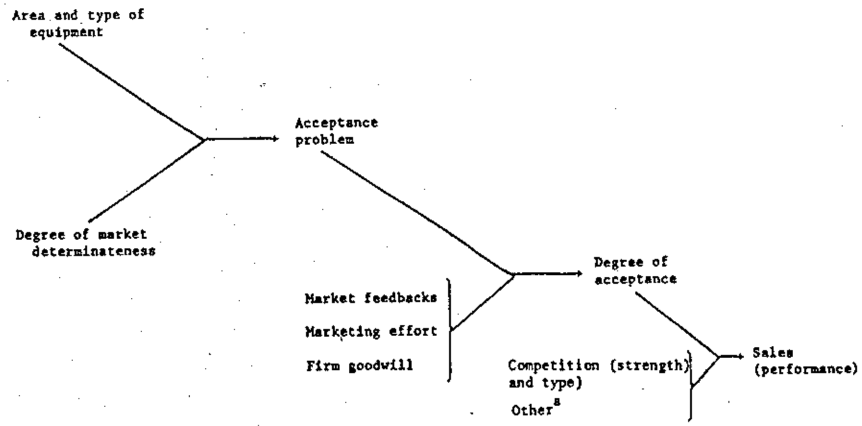
*Product acceptance:* Product acceptance is a measure of the willingness of users to consider the product when a purchasing decision is to be made [variable (c)]. It is a necessary condition for a product to be demanded, but, for at least two reasons, not a sufficient one: the timing of a user's purchasing decision may be independent of the acceptance times of the various alternatives; and a particular accepted product has to compete with other accepted products. Thus, acceptance and competition jointly determine the demand for a product+.

* The discussion which follows is summarized schematically in fig. 1.

** In general, the discrepancy between (b) and (c) is due to one or both of, first, spectrum effects (mentioned above); and second, the extent to which users are willing to purchase from a firm despite the uncertainty surrounding the objective capacity of the product to satisfy their needs, thus (c) will depend in part on the firm's goodwill.

\+ Partial acceptance of new biomedical products is gained after successful tests by recognized specialists in the field and publication of the results.






[a] E.G. program attributes such as innovation profile, area variables such as market size and growth and firm characteristics such as firm size.

Fig. 1. Market determinateness and performance.

We can now specify the two variables or groups of variables determining product acceptance: first, the degree of market determinateness, second, the variables (α)–(γ) – extent of market feedback, marketing effort, and the firm's goodwill. The degree of market determinateness determines the magnitude of what can be termed the acceptance problem which has to be overcome for success, and, for given levels of (α)–(γ), the risk of not gaining enough acceptance fast enough to ensure success (acceptance risk)*. Variables (α)–(γ), to which may be added the passage of time, determine the extent to which the acceptance problem had been overcome. *Ceteris paribus*, the greater the acceptance problem the greater the marketing effort required for success.

*Influence of other parameters:* The seriousness of the acceptance problem (even within a given category of market determinateness) is a function of other parameters as well, such as area, type of instrumentation, and the characteristics of users.

In some areas the existence of a clearly perceived need is all that is required for immediate acceptance. For example, a completely new drug whose purpose is to cure acute cases of cancer may be tried and accepted almost immediately. The lack of complete information on its effects may not be so relevant for treatment of critical cases. Alternatively, a new pacemaker, even if completely standardized, may involve a serious acceptance problem: lack of

* Acceptance risk should be distinguished from another market risk which derives from competition.

minimum information may have serious consequences for the ultimate user. These extreme examples suggest that the acceptance problem of strongly determined products in some areas may be greater than the acceptance problem of weakly determined products in other areas*. In biomedical electronics, the acceptance problem may be less serious for diagnostic equipment (in any category of market determinateness) than for monitoring or therapeutical equipment. We conclude that the correlation between the degree of market determinateness and the magnitude of the acceptance problem may hold only within a given area**. Similar considerations would hold for the type of equipment developed and the characteristics of users in any given area. Thus the more complex the equipment and the greater the number of users, the greater the acceptance problem.

*The findings*

Each R & D program was allotted to one of three market-determinateness categories: *low* (or *weak*) – unknown products (with or without a clearly defined need; corresponding to categories 1 and 2 of table 5); *medium* – known products whose function is not fully standardized (category 3 in table 5); and *high* (or *strong*) – known products with standardized basic function (categories 4 and 5 in table 5).

*Low market determinateness*
(a) The specific function of the new product was being performed before by other means, either more imperfectly or more expensively, or both.
(b) The specific function of the new product was not being performed by other means before the appearance of the product.

*Medium market determinateness*
(a) Products designed for experimental purposes which have not yet reached the stage of standard clinical application.
(b) Products which perform a basic function which is already standard in some clinical applications but in a radically different way. In this case the

* Within each of these extreme areas, our market determinateness categories would probably not reflect strongly varying magnitudes of the acceptance problem and would presumably not differentiate success from failure.
* In a wider framework, the distinction between areas involving final consumer goods and those involving producer goods may also be relevant.



product may be suitable for existing applications or it may create new applications or both.

*High market determinateness*
Products whose basic functions are standard in some clinical application.

Two comments on these categories are in order. In the low market-determinateness category, we can be sure that the products satisfy a *specific* need only in the case of (a). The products of R & D programs in (b) probably do not satisfy a well-perceived specific need but may still satisfy a more general or a latent need. In the medium market-determinateness category the issue arises as to when the introduction of a radically new way of operation makes the basic functions of an instrument less standard than they are according to the conventional method or working principle* (see footnote on p. 373). The distribution of successes and failures among the three market-determinateness categories can be observed in table 6.
Several conclusions can be drawn from the table. First, the proportion of

Table 6
Success and failure, by market-determinateness category

| | Total | Market-determinateness category | | |
|---|---|---|---|---|
| | | High | Medium | Low |
| *Number of programs* | | | | |
| Failure | 18 | 4[a] | 7 | 7 |
| Success | 5 | 5 | – | – |
| Total | *23* | *9* | *7* | *7* |
| *Per cent of total R & D costs* | | | | |
| Failure | 51.9 | 32.0[a] | 10.2 | 9.7 |
| Success | 48.1 | 48.1 | – | – |
| Total | *100.0* | *80.1* | *10.2* | *9.7* |

[a] Additional information may lead us to reclassify two R & D programs involving 25.8% of total R & D costs into the medium market-determinateness category. In this case, our conclusions will be reinforced.

* In a more general framework, the criteria for deciding whether or not the introduction of new technology into existing products reduces their market determinateness should take account of (a) the extent to which the new technology is visible to the user; (b) the extent to which the new technology requires adaptability on the part of the user. These factors were mentioned to us by D. Rosenbloom.

successes drops to zero as we go from the high market-determinateness category to medium and low. Second, the number of failures increases as we go from high to medium or low. Third, most programs with high market determinateness are successes and most of the R & D spent in this category is associated with success. We may thus state that

> The degree of market determinateness differentiates sharply between the successful and the unsuccessful biomedical electronics R & D programs studied. There is no need, in this connexion, to differentiate areas and types of instrumentation*.

## ANALYSIS: THE INNOVATION PROFILE

The innovation profile underlying a particular R & D program involves both the technical (new-product) component and the price of the program's product, both in relation to products already in the market. In this study we distinguish three innovation categories referring to the technical component.

A. Completely new instruments.

B. Similar instruments exist, but the product of the R & D program seeks to perform the basic functions of the instrument in a radically different way, a way which is new in the existing fields of application.

C. The products of the R & D program perform the basic functions of existing instruments in basically the same way** although usually more efficiently+.

The innovation categories are related to the market-determinateness categories, although – with the exception of A which is equivalent to the low market-determinateness category – they are not identical with them. Thus

* This result is consistent with the findings of Jones ([5], pp. 18–22) concerning what he terms the leading problems facing a sample of 265 biomedical firms. "Determining Product Requirements of the Market" and "Achieving Market Acceptance" were considered to be leading problems by the greatest and third greatest number of firms, respectively (*ibid*, table 15).
The result also fits in with Hirsch's qualification [8] to his main product-cycle model result which states that small developed countries have a comparative advantage in new products. The range of new products for which this is true narrows when export marketing (including feedback and the collection of market information) is much more expensive than domestic marketing.

** The introduction of new components into existing instrumentation often fits in here.

\+ E.g. with higher data processing and display capability, patient safety, and reliability; and more simply and comfortably.



category B includes R & D programs with both medium and high market determinateness, i.e. a radically new way of performing an existing function may or may not change the standard functions and applications of the instrument+. In addition, R & D programs in category C need not have high

Table 7
Distribution of programs and R & D costs by degree of market determinateness and innovation category

| Degree of market determinateness | Number of programs in innovation category | | | R & D share (%) in innovation category | | |
|---|---|---|---|---|---|---|
| | A | B | C | A | B | C |
| Low | 7 | – | – | 9.7 | – | – |
| Medium | – | 4 | 3 | – | 6.4 | 3.8 |
| High | – | 2 | 7 | – | 25.8 | 54.3 |
| Total | *7* | *6* | *10* | *9.7* | *32.2* | *58.1* |

Table 8
Performance by innovation category

| | Total | Innovation category A | B | C |
|---|---|---|---|---|
| *Number of programs* | | | | |
| Failure | 18 | 7 | 6 | 5 |
| Success | 5 | – | – | 5 |
| Total | *23* | *7* | *6* | *10* |
| *R & D share (%)* | | | | |
| Failure | 51.9 | 9.7 | 32.2 | 10.0 |
| Success | 48.1 | – | – | 48.1 |
| Total | *100.0* | *9.7* | *32.3* | *58.1* |

\+ A radically new way of performing an existing function is likely to change its efficiency in various directions. If efficiency in existing applications increases, the new product will be considered strongly market determinate if the existing function and applications were already standardized. (In this case, there will be a widening of the field of application of the function). If efficiency increases in one direction and decreases in another, existing standards in function applications are not relevant in regard to the new product and new standards should be created. In this case the program is only of medium market determinateness and there may be a decline in the instrument's range of application.

market determinateness if the basic function-applications relation has not yet been standardized. The relation between innovation category and market-determinateness is illustrated in table 7*.

The distribution of success and failure by innovative category is shown in table 8. We can see that all the successes belong to category C. In addition they also belong to the high market-determinateness category in table 7. We can thus say that

> A necessary (but not sufficient) condition for an R & D program to be successful was that the products of the program perform the central functions of existing instruments in basically the same way, usually more efficiently (category C)**. In addition, a higher share of the R & D costs of programs satisfying this condition was associated with success than with failure.

This conclusion can be interpreted as follows: R & D programs belonging to category C which are only medium market determinate are likely to be market failures while strongly market-determinate projects belonging to category B may fail technologically+.

*Price comparisons*

We have referred to the technical side of the product innovations covered in this report while almost completely neglecting their price. A complete characterization of an innovation, i.e. the innovation profile, must also consider this element and relate it to existing competing products. At least two aspects of price seem relevant, a comparison of absolute prices; and a comparison of prices per efficiency unit in the performance of basic functions++. The relative importance of the latter seems to increase as basic functions and their applications gradually become standardized. When a particular basic function–application has yet to be standardized, i.e. when objective yardsticks for performance in specific applications have not yet been established, it may be more problematic to translate an increase in function efficiency into medical terms.

* It can be seen that two programs in category B representing 25.8% of total R & D have strong market-determinateness while three programs (representing 3.8% of total R & D) in category C have medium market determinateness.

** A large proportion of R & D programs in categories A and B were undertaken under considerable technological uncertainty. All except two of the programs were either weak or medium market determinate. It would seem that a high degree of risk, either market or technological or both, accompanied these two categories.

\+ A more rigorous analysis of failure goes beyond the scope of the present paper.

\++ By definition price comparisons cannot be made for programs belonging to category A.



*Alternative profiles*

Given its objectives and constraints, a firm should decide on the innovation profile which will maximize its chances of success in the R & D programs or program it intends to undertake. We attempt to relate innovation profile and performance only for category C since it is only here that we find both successful and failed R & D programs. For the same reason we consider only those programs which are highly market determined (table 6). This leaves us with a set of seven programs covering 54.3% of the investment in R & D.

All the programs in the set showed an increase in function-efficiency per unit of cost, but the question we ask is whether the main thrust of the innovation lies in increased technical efficiency or in decreased cost. For this purpose we divide these programs into two profile sub-groups.

$C_1$. Significant improvements in function-efficiency with a price which is either similar to or above the price of competing instruments.

$C_2$. The new instruments might include improvements as in $C_1$ but they are less significant, the emphasis being on reducing the price of the instrument compared with competing products.

The distribution of success and failures between $C_1$ and $C_2$ is shown in table 9 from which we infer

> All highly market-determinate programs in category C involving a significant improvement in function efficiency and selling at an equal or higher price (i.e. profile $C_1$) succeeded.

Table 9
Performance of strongly market-determinate programs in innovation category C

| | Total | $C_1$ | $C_2$ |
|---|---|---|---|
| *Number of programs* | | | 2 |
| Failure | 2 | – | – |
| Success | 5 | 4 | 1 |
| Total | *7* | *4* | *3* |
| *R & D share (%)* | | | |
| Failure | 6.2 | – | 6.2 |
| Success | 48.1 | 46.9 | 1.2 |
| Total | *54.3* | *46.9* | *7.4* |

Two out of the three highly market-determinate programs (and most of the R & D expenditure) in category C whose main thrust lies in price reductions failed.

### *Type of competition*

A possible explanation for the positive relationship between performance and the emphasis on increasing function efficiency (in contrast to, and even at the expense of, reducing the price) lies in the type of competition in the biomedical market. Competition is mainly based on subjective confidence in supplier and quality, and not (predominantly) on price.

Knowledge of the relative importance of (a) quality and servicing efficiency versus price; and (b) quality and servicing efficiency versus subjective confidence in supplier, may enable firms to plan their strategy more efficiently Six of the nine firms explicitly ranked the relative importance of price, quality, servicing efficiency, and subjective confidence in supplier. Two gave different rankings for each of two projects, and in one case the first place was given to two factors.

We summarize the findings briefly.

(1) Subjective confidence in supplier is ranked as the dominant form of competition (and consequently as the most important factor for success) in most cases (5 out of 9).

(2) In the remaining cases, quality and servicing efficiency (the same number of cases for each) were referred to as the dominant form of competition.

(3) In no case was price considered the dominant form of competition.

Despite the small number of observations and the lack of direct evidence from users on the dominant forms of competition, the results coincide with those obtained in a recent study*. They suggest several interesting points. The importance of subjective confidence in supplier is a direct result of users' lack of complete information about the performance characteristics of the products purchased**. This is why firm's goodwill affects the degree of

* R. D. Peterson and C. R. MacPhee [3] have emphasized the dominance in the purchasing decisions of 246 medical-care professionals of "non-perceptible" differences in products (such as firm's reputation and recommendation of colleagues) over "perceptible" differences (such as quality and price). Moreover, the various aspects of quality (specifications, safety, ease of operation, etc.) were all more important than price in determining purchasing decisions.

** The lack of information refers to both quality and servicing, but it is probably more acute for servicing. This is because at least some aspects of quality can be perceived at the time of purchase. But servicing is only provided in the future so its objective evaluation in the present is difficult.



acceptance achieved (see fig. 1). Recent entrants into the biomedical field will very likely not enjoy the confidence of their potential customers: their competitive edge must be in the possibility of supplying higher quality products.

In general a small unknown entrant should, in view of the forms of competition dominant in the industry, begin by offering goods whose objective quality is high and easily perceptible, and whose servicing requirements are demonstrably small. Easily perceptible quality and small servicing requirements reduce the uncertainty due to lack of complete information and they therefore reduce the importance of subjective confidence in supplier (the factor which is not available to new firms). Instrumentation which satisfies these two conditions is characterized by two features: it is simple (and small) and its functions are standard (making easy evaluation of performance possible)*. If customers' expectations concerning the first products are confirmed, subsequent sales will enjoy greater confidence, which might enable the firm to increase the size and complexity of the systems developed. Because of the general acceptance problem discussed above, development of products incorporating unstandardized functions is even then not recommended.

The implied relatively low elasticity of demand with respect to price merits careful analysis. Here, however, we can only sketch some of the implications. Lack of search time and inadequate information on alternative products does not permit users to consider simultaneously all the quality-price features of all alternatives. The result is a process of choice and rejection by stages, starting with quality or confidence in supplier and only then proceeding to price comparisons. Much more remains to be done in conceptualizing this kind of purchasing decision.

## CONCLUSIONS

(1) The report has isolated a reduced set of variables which are correlated with the innovation performance of firms belonging to the Israeli biomedical electronics sector. The central variables are market determinateness (an area characteristic) and the innovation profile (an attribute of R & D programs). The nature of the idea leading to R & D programs, the type of competition prevailing in the industry and the notion of product acceptance all complement the main explanation given by these two variables. Consideration of

* These conclusions again complement those reached in connexion with market determinateness (with the additional point that a simple reduction in price will not work).

additional program, firm, and area variables – such as the spectrum of products offered by the firm, market and firm size, and rate of growth – will undoubtedly contribute further to our understanding of performance in innovation. This task is left for a later stage.

(2) Since the objective access to markets and market information does not seem to have differed much between firms*, it follows that differences in performance at the R & D program level basically reflect differences in management, i.e. in the extent to which the variables mentioned above were taken into account in the strategic decisions of the firm.

(3) Although the variables selected for the study managed to explain performance of past biomedical–electronic R & D programs, we should be cautious in using them to predict performance of future programs without taking into account changes in the characteristics of the firms involved. For most of the programs studied, the firms were small, or newcomers to the field or scientific entrepreneurs or all three. Their size has now changed and also their approach and strategy – and in some cases the time may be ripe for taking a calculated risk in a promising new area despite its not being very market determined.

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* For example when comparing the performance of American and European firms in science-based industry, an OECD study argues that the relatively greater access to the United States market of firms in the United States has been a significant contributing factor. See ref. [10].



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