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RESEARCH-BY-OBJECTIVES, TECHNOLOGY TRANSFER, AND MARKET EVOLUTION: A VIRTUOUS TRIANGLE

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Abstract

The approaches normally followed for building up a research program are no longer suitable for high technology and, specifically, for microelectronics. A closer link with the exploitation phase is now necessary not only for economic but also for social reasons. A new concept, here called research by objectives, is described; it foresees a natural link between the technology transfer phase and market evolution so as produce a virtuous triangle.

1. Introduction

We normally distinguish between basic and applied research. Nowadays this separation does not highlight (I believe) a key difference. Instead, we should classify research activity into actions that aim directly at the production of health and studies that are inspired by cultural needs. The first category should be further sub-divided into Research by Objectives (RBO) (where the key objective is the health of a company, a corporate, a country, a geographical area, etc.) and Research on Demand (ROD) aimed at solving contingent problems. The former entails looking at the future, the latter mostly concentrates on the present.
Neither RBO or ROD are justified without a suitable fallout into the market and, at the same time, without market drive. These mechanisms are quite natural for ROD; by contrast, for RBO they are much more complex, both to activate and to control. Technology transfer (TT) activities ensure the link between research and market (M), thus, forming a (possibly virtuous) triangle.
This paper concentrates on RBO, TT and market evolution in the microelectronics area. However, an extrapolation to other fields is straightforward.
We will start by considering the more commonly applied research policies (which are mainly no-RBO plans) and we shall analyse their limits and risks. Mechanisms for technology transfer will then be addressed and finally the difficult task of microelectronics forecasts will be considered. These elements will be essential in introducing the new approach proposed: RBO. The key idea will be discussed and afterwards, some indicators important for the practical implementation of RBO will be mentioned. The following considerations will hopefully favour mechanisms to make the ROB-TT-M triangle virtuous for general health production.

2. Research Programmes

For decades our societies have been based on two key ingredients: *labour and capital.* Now we are rapidly moving toward societies based on *knowledge and capital* (labour is becoming less and less important). This is particularly true for microelectronics where the incidence of labour (blue collars) on the final cost of products is less than 10% and the contribution of raw materials is only around 5%. Therefore, achievements of microelectronics, as well as of other high-tech disciplines, are knowledge-intensive goods. For this we have to concentrate on the generation of knowledge and, most importantly, we have also to consider the defence of knowledge and its rapid transformation into solid benefits.
Knowledge is principally generated by research. However, with present approaches defence and fast transformation into benefits are rarely achieved. Research generates new concepts, people look for possible applications and finally industry seeks suitable mechanisms to transform concepts into new products. This pipeline approach [1] takes a long time and leaves unexploited ideas without a solid defence (we have to point out that the best defence of technical achievements is time and not secrecy).
In order to better understand the limits of present approaches and to identify new routes to progress it is worthwhile considering the present research scenario and to classify its different facets from the point of view of their most critical aspects. We can distinguish between:

a) *Unfettered programs*: they have no real constraints: research is driven by the cultural curiosity of participants. This category, that includes most of the "basic research activities", conforms to a reflection by A. Graham Bell [2] that says: *"Leave the beaten track occasionally, and dive into the woods. You will be certain to find something that you have never seen before."* The true problem with this key (and profoundly valid) assertion sits into the interpretation of the word "occasionally".
b) *Wide theme programs*: the boundaries are weakly defined; the titles can be, for example, *'Advanced technologies for sub-micron devices'* or *'Tools and methods for signal processing'*. This class is, in general, well accepted by potential participants since any interpretation of the title can fit specific technical interests. However, relationships between different activities hardly exist and soon programs break down into uncorrelated projects.
c) *Glamorous theme programs*: researchers find satisfaction (and often have a successful carrier) showing abundant innovative results. Getting them is much more easy when working in emerging areas; this is the reason why any new field is over-encouraged quickly becoming a new fashion capable of inducing public opinion's curiosity. The over-expectation created by the glamour of these new fields leads to programmes with excessive funding; after an overshoot of interest these topics settle to a more reasonable level of fascination. Neural networks are the last example of this category.
d) *Research on demand (ROD) programs*: this category has been already mentioned; it derives from a bottom-up process generated by short term specific needs (and not overall interests). The push towards research activity comes

from the direct beneficiaries of the results; very often big companies. The founding bodies consent because of the political weight of the proposers and because public opinion (for lack of specific culture) is mainly sensitive to short term benefits.

The above distinction into categories is meaningless in terms of what Robert Reich, in his *The Next American Frontiers* [3], defines as the 'first path' which *toward stable mass production, relies on cutting labour costs and leaping into wholly new product lines as old ones are played out. For managers this path has meant undertaking (or threatening) massive layoff, moving (or threatening to move) to lower wage states and countries, parcelling out work to lower cost suppliers, automating to cut total employment, and diversifying into radically different goods and services.* The shift in emphasis from 'the fist path' (hands) to 'the second path' (brains) that through *collective entrepreneurship, involves increasing labour value,* makes the role knowledge plays more important (its generation, control and exploitation) in *re-training employees for more complex tasks, automating in ways that cut routine tasks and enhance flexibility and creativity, diffusing responsibility for innovation.* The above considerations indicate that it is important and urgent to reshape research plans in order to quickly keep pace with present evolution and, at least, avoid the following limitations:

1) *Blindness*: this is typical of research activity without solid guidelines; very often researchers (especially in universities) do not know what is important; they are insulated from the productive context and grope in the dark. In these conditions if they get valuable results these are left in the air and anybody can take and exploit them.
2) *Poor concreteness*: sometimes research concentrates on aspects that can be important for a deep understanding of phenomena but they are irrelevant for producing health. In other cases research seeks to achieve the same results already achieved by others but by going the other way around.
3) *Good for others:* high-tech research means use of high-tech (for example super-computers, workstations, CAD tools, instrumentation, etc.). If the high-tech goods used come from outside we will mainly produce health for competitors.
4) *Lack of "just in time"*: results of research that come much too early for their commercial exploitation are difficult to defend; on the other hand late results may contribute only to follower activities.
5) *Low coverage*: exploitation means knowing and solving all the related aspects. Often research concentrates on the charming parts and leaves "trivial" particulars aside. An example is given by present studies on sensors that only marginally consider packaging and reliability.
6) *Inadequate surrounding*: research can be directed, protected and exploited only under suitable boundary conditions. These should comprehend strategic importance, create adequate infrastructures, pursue development policies and look out for the general interest.

From the previous discussion we can conclude that, for future needs, the only (barely) suitable class is ROD. However, it pursues short term objectives and it is driven by a narrow spectrum of interests, therefore it alone is not adequate for long term generation of health.

3. Technology Transfer (TT)

Results of research activity are translated into market benefits by technology transfer. This step is very critical: the failure to convert research achievements into commercial enterprises seriously hampers industrial competitiveness and, in turn, it hinders the possibility of founding new research plans.
Technology transfer must be, essentially, a science and technology thoroughfare that should be free, as much as possible, from bureaucracy and legal impediments. Also, in my opinion, it must be a knowledge diffusion process that moves from the places where the technological culture is produced spreading towards prospective beneficiaries; this, principally, to increase awareness of the strategic value of high-tech.
For efficient technology transfer an a priori matching of needs and offers is necessary. In the present situation, we need communication channels to spread information about what research laboratories offer, how and for what it can be used and what companies really need. Following this, legal instruments and stimuli must be devised. Examples of legal instruments are the Cooperative Research and Development Agreements (CRADA) made possible by the US Federal Technology Transfer Act (1986) and the National Competitiveness Technology Transfer Act (1989) [4].
However, the real stimulus for TT derives from culture. Societies based on individualism easily produce knowledge but they have impediments in TT. By contrast, we have an opposite effect in societies based on collectivism (at least theoretically). Therefore, in the Western world TT must be promoted. One possibility is to use economical incentives by paying part of the royalties of exploited patents to inventors working in government or company laboratories. Another is to encourage people to become "agents" of technology transfer [5] that goes directly to the prospective end-user and shows them the results of innovation. This has two advantages: the impact is greater than sending a letter, a report or a manual (it is difficult to ignore a well-meaning person) and it helps to make the low coverage (when it exists) of results offered obvious.
However, problems of TT are now structural: it is very difficult to obtain matching of offers and needs because most present activities in laboratories and universities are affected by one or more of the limitations mentioned in the previous paragraph: blindness, poor concreteness, lack of just in time and low coverage are so recurrent that to achieve "right offers" laboratories should stop developing anything supplied more economically by industry and instead develop core capabilities useful to allow industry to make better products [4]. Universities should stop working in a vacuum [5] and instead direct their efforts ahead of industrial needs. On the other hand, industries should pursue technical targets that are advanced (and risky) enough to make the contribution of laboratories and universities essential.

4. Market Forecast

Research activities induce knowledge for future demands and set a route for the market. The market evolves according to development of knowledge and pro-

duces inputs for research activities. This loop of progress is controlled by decisions that are always taken on the basis of forecasts: determining how to invest in fuzzy logic depends on the future market penetration of these techniques. Huge efforts spent on submicron technologies are justified by forecasts of new massive products. Research on new packages is stimulated by expectations in the new area of personal communications; and so forth.

An obvious risk of forecasts lies in their uncertainty. This, in the past, was accepted because of the advantages of anticipating strategic actions with respect to competitors. However, erroneous decisions can be catastrophic; an example is given by the personal computer whose penetration in the market was highly overestimated. This wrong prediction is the principal reason behind the recent crisis of the electronic market. Therefore, forecasts with an high degree of reliability will be essential for the future.

This is not the case nowadays: many forecasts for microelectronics seem to be just linear or quadratic extrapolations of past events without showing any degree of uncertainty. Very often these approximated forecasts are used for funding requests or for defining strategies. The art and science of forecast is so complex that it is presumptuous to judge its outcomes. However, I believe that it will be necessary to continue to refine models to also account for multiple non-technical elements (political status and its evolution, human habits, culture and the solidity of tradition).

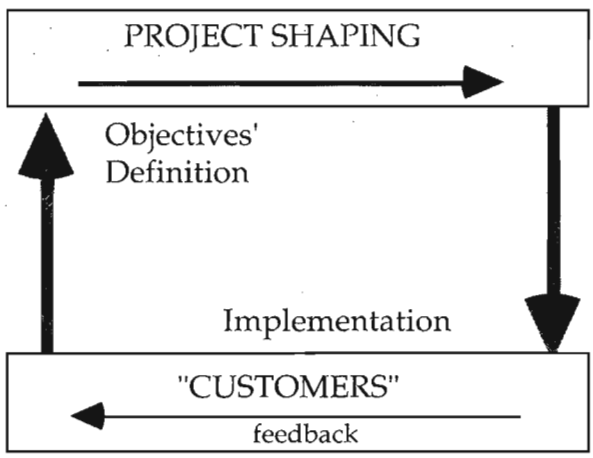

Fig. 1 - The RBO flow

5. Research by Objectives

Research by Objectives is not just a technique for building up research programs, it is a new way of thinking, that, probably, at the beginning will be opposed by many researchers. Present research activity is mainly incentivated by the Esteem/Recognition and Self-Actualisation needs (the two highest steps of Maslow's needs hierarchy) of individuals. By contrast, RBO is an answer to the Esteem/Recognition and Self-Actualisation needs of organisations (or societies). The two things seems to be opposed to each other; nevertheless, RBO will be successful only if we are able to harmonise the highest needs of individuals and organisations.

RBO is also a method for optimising the effectiveness of research efforts because it makes global objectives a guiding light. RBO is a two-way journey. The first defines objectives, the second their accomplishment (Fig. 1). An RBO project is activated by a problem or a need; a "customer" manifests it to the body in charge of research definition. The problem/need is then exposed to the critical analysis of other "customers" and (very importantly) independent evaluators to identify wider objectives whose accomplishment contains the solution/satisfaction to the original problem/need.
In the first journey we have the following steps (Fig. 2):

- *React critically*: the problem/need arisen often sounds like criticism for the body in charge of research definition. Thus, frequently, the reaction is hostile. Instead it should provoke inspection of the policies followed and presumably a subsequent exploration of possible actions. If the result of this phase is trivial the point is rejected and the proposer is properly directed.

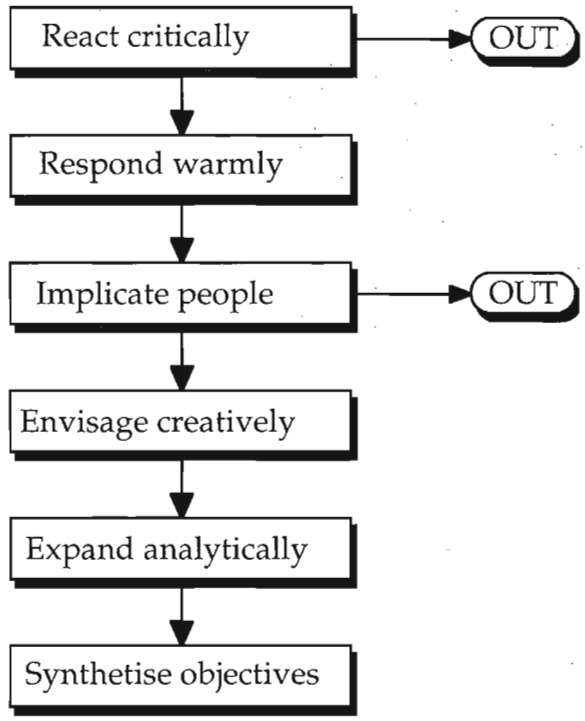

Fig. 2 - Steps of the Objective Definition journey

The key aspect for this first step is that official bodies should have suitable arrangements to favour a bottom-up flow of problems/needs.

- *Respond warmly*: when a problem is pointed out and accepted as credible all the efforts must be made to activate the institution that manages the research. A warm response gratifies the proposer and foreshadows a cooperative climate.
- *Implicate people*: no matter how brilliant and sensitive the individuals initially involved may be. Personal (limited) visions do not permit the exploration of all the potential aspects. Meetings, exchange of information and brainstorming must therefore be stimulated. Results of this step can also lead to the decision to end the process.

- *Envisage creatively*: the use of creative fantasy allows us to visualise future scenarios. This is the basis for the identification of long term objectives.
- *Expand analytically*: the problem/need arisen should be expanded according to the view of other "customers" so as to define objectives aimed at general health and not just at the health of a few individuals (very often the proposers).
- *Synthetise objectives*: this is the last step that generates the output of the journey considered. The objectives should envisage a proper balance between short term and long term achievements.

The horizontal branch in the diagram in Fig. 1 defines the shaping of the project. This phase comprises an a priori definition of legal instruments and the setting up of the necessary organisation. The shaping of the project should also include a "simulation" of the implementation journey in order to anticipate problems and critical points and to find solutions.

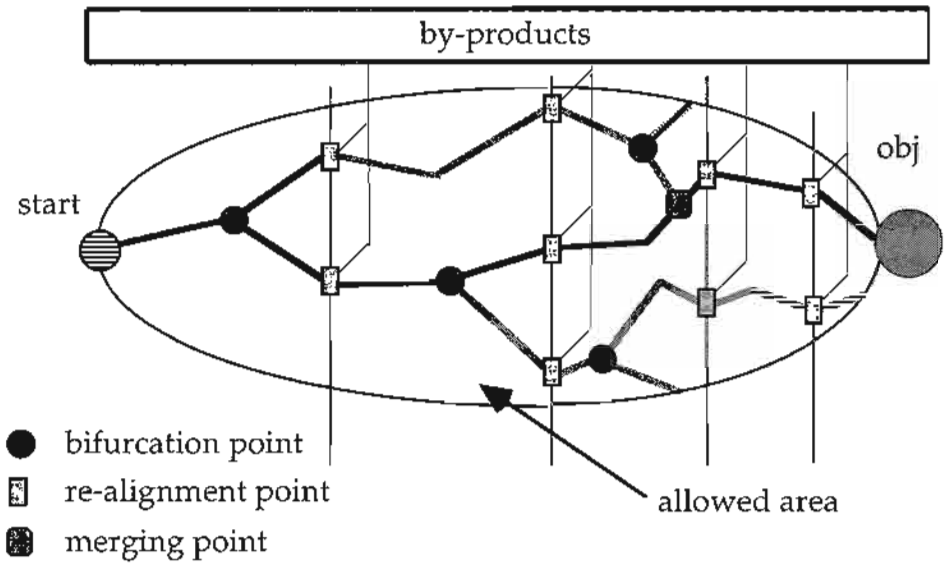

Fig. 3 - Schematic representation of the journey toward the objectives

The implementation journey is a path in a multi-dimensional space (time, basic knowledge, technology, manpower skills, tools and methods, infrastructures, social situations, competitor's position, etc.). It moves from the "starting point" and (possibly) achieves the objectives following the schematic represented in Fig. 3.
We have three significant categories of points: the bifurcation point, the re-alignment point and the merging point. The first one, either resulting from a strategy or even naturally generated, should be made profitable because it favours competition and allows the exploration of more than one possible path.
The re-alignment point results from periodic verifications: when the status lies outside the "allowed area" the route followed must be abandoned, or the direction can be suitably adjusted having the final objective as continuous reference. A suitable number of indicators permits us to assess the status of the projects. Key indicators are: technology and application trends, basic knowledge inventory, tools/equipment needs, manpower skills, quality and impact. Re-alignment

should also depend on the level of acceptance of technological innovations: it is strongly influenced by human habits, culture and reactions from tradition. In essence, re-alignment means changing direction in multi-dimensional space; this may even signify launching new activities in basic knowledge, study new technologies, and so on.
The re-alignment points have another important function: the extraction of by-products. Not all the results achieved are suitable for reaching the objectives (for this re-alignments are necessary). Nevertheless, most of these are valuable and could produce benefits in a different context. Afterwards the identified by-products must therefore be directed towards other projects managed by the same or by parent organisations. Finally we note that the check points become more frequent as we approach the final objectives. These inspection points may occur at the same time for all the different explored paths (as shown in the figure) or can be planned at different times.
The merging points permit an optimisation of resources. They are naturally favoured when the different paths followed become so close as to make the difference between activities minimal.
The limits in length of this paper do not allow me to enter into further detail. However, it is important to keep in mind five key rules for the success of an RBO project:

1 produce measurable results
2 pursue short term and long term objectives: the short term achievements must be the first step in a long term process
3 stimulate and meet the Esteem/Recognition and Self-Actualisation needs of researchers involved
4 research is not only one thing but three: improvement, managed evolution and innovation [6]
5 RBO must create a virtuous triangle together with technology transfer and market

The last rule coincides with the title of this paper; it also corresponds to the feedback path in the customer block in Fig. 1. We will discuss this point in more detail in the successive section.

6. Closing the Loop

An RBO project is an activity aimed at producing health. This signifies, in the ultimate analysis, that we have to satisfy needs at higher levels of Maslow's motivation hierarchy. We can achieve such a target by favouring the production of goods capable of increasing the level of satisfaction of people and not by stimulating desires for goods consumption. Another crucial meaning of RBO lies in the increase of labour value by motivating the re-training of employees and by stimulating creativity; this should be achieved together with a substantial increase in knowledge-massive employment.
Therefore, the loop around an RBO project should enhance only tasks that are relevant to these ends. In other terms, we need to dispense, allocate, and use research results as a way to deliver *task-relevant feedback* [7]. Feedback around RBO is

closed by technology transfer and market. Thus, market becomes the "customer" at the input of RBO that evolves according to the quality of knowledge that it receives. However, the inputs from the market do not always lead to general health. For this reason, it is very important to accept only virtuous inputs from the market to produce a virtuous triangle made of RBO, TT and market evolution.
In tomorrow's society, if we want to create high skill, highly paid jobs, which are less vulnerable to harsh competition from even lower wage producers, I believe that this approach is the only feasible one.

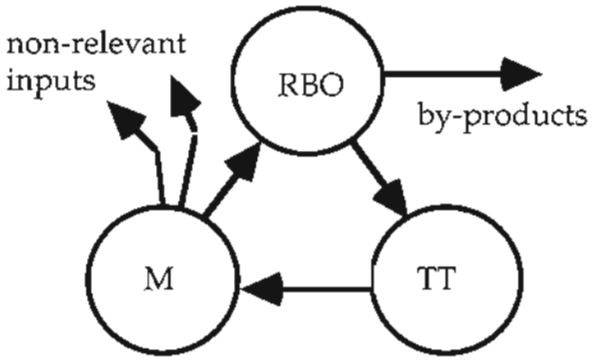

Fig. 4 - Feedback loop around RBO

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