A Simple Model of R&D Activity and Implications in Technology Development of a Territory

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Introduction

Experiences in promoting technology innovation in a territory show that the relation between the amount of financing R&D projects and subsequent generation of successful new technologies is far to be proportional but quite complex. In fact, it seems that a real technology development of a territory is possible only when a critical level of financing of R&D has been exceeded, otherwise a situation of stagnation or even decline of the technological activity is observed.

In order to show the possible existence of critical levels of R&D financing for technological development we have elaborated a simple model of simulation of R&D activity and studied the generation of R&D projects and subsequent new technologies in function of various forms of financing and generation of R&D projects. In order to develop a model for R&D activity we have basically used the domain view of R&D described by J.H. Dumbleton (1986) which was inspired by the classical work of J.D. Thompson (1967) on organization activities. Although such original view has been made thinking to the internal R&D activity of a single firm, we may easily extend it to a territory where numerous firms interact, compete and cooperate in the same socio-economic and techno-scientific structures.

Using the model we have simulated various situations of the R&D activity allowing quantitative predictions in term of number of project proposals and R&D projects as a function of two types of available financing: the first one, we called industrial, is the normal way with which financing of R&D is carried out, the second one concerns venture capital that has its own specific way to finance R&D. Running the simulation model we have considered a territory with an initial low level of R&D activity looking for critical values of parameters that may start or not a real technological development. The obtained results arise a certain number of implications that should be considered when promoting R&D activity in a territory with the aim to generate technological development with its positive socio-economic impact.

Model of research & development activity

In this model the R&D activity, considered composed by a certain number of R&D projects, is seen as a simple black box with input and output without entering in detail on inner processes existing in running the various R&D projects. The number of projects is determined by the financed R&D proposals and may be limited either by available financing or available valid proposals. Both financing and proposals constitute the input for the R&D activity. The output of R&D activity is essentially constituted by information. Following the basic view of Dumbleton (1986) the flux of information generated is of various type and separates in two directions, the first one, we may consider internal, is constituted by reports, samples, prototypes, meetings, etc. and is exploited by the socio-economic system of the territory to evaluate and decide whether the new technologies shall be industrialized or not, the flux in the second direction, we may consider external, is constituted by publications, patents, presentations, informal discussions, etc. that are essential to generate new ideas and valid proposals for new R&D projects.

A key aspect of the model concerns the way valid proposals for R&D projects are generated. The basic idea is that the process generating new ideas for R&D proposals is of combinatory nature and autopoietic in the sense that existing and past R&D projects are essentially the basic source of new R&D projects. The combinatory and autopoietic nature of new technologies has been recently discussed by W.B. Arthur (2009) in its book on nature of technology. Following this author new technologies are the result of a combinatory process of past technologies and technology innovation process should also be necessarily combinatory. Modeling technologies you can consider a technology as an artifact constituted by components, for example, motor, brakes, wheels of a car, but also as a process constituted by a sequence of technical operations necessary to build up the artifact or even as a process that makes possible the artifact to work. The technology innovation may be also seen as the result of combinatory activity of components or processes. Previous work using combinatory aspects of technologies have been published about innovation obtained by learning by doing (L. Auerswald, S. Kauffman, J. Lobo, K. Shell, 1998)) as well as in planning experiments for R&D activity (A. Bonomi, A. Riu, M. Marchisio, 2007). Designing new technologies, in terms of components or processes, may be seen as combinations of information coming from existing or past R&D projects, but not only, because there is also an important role played by scientific information. Science, as observed by J. Fleming and O. Sorenson (2004), acts in fact as a map in technological search limiting the field in which a technological innovation have a large probability to be found. As observed by W.B. Arthur (2009), there is also another very important role of science consisting in supplying to technological search new phenomena that may be exploited for innovation. For example: thermodynamic science is very useful in developing new metallurgical processes by indicating ranges of temperature, concentrations, etc. in which there is a good probability that the envisaged process may occur, on the other side a new technology, such as laser, is constituted by classical electronic circuits made by well known procedures but combined in such a way that a new discovered physical phenomena, such as coherent emission of light, may be exploited for example in reading CD or DVD disks. Of course, only a limited part of possible combinations of information may lead to valid R&D project proposals and finally to financed R&D projects. The rate of generation of valid R&D proposals can be seen as a measure of the efficiency of the techno-scientific system of a territory.

Another important aspect that should be considered in the model is constituted by the probability that financed R&D projects become successful technological innovations. Such aspect is important when discussing for example managing of technical risk in early stage R&D projects. These arguments have been for example the object of a report of the US Department of Commerce (L. Branscombe, K. Morse M. Roberts D. Boville, 2000). This document shows clearly as successful results of innovations originated by R&D projects are skew distributed and long times such as five to ten years are often necessary to assess the success or failure of new technologies.

It is important for R&D modeling to define the conditions of success of an innovation. Technology innovation is not necessary the exclusive result of R&D activities that are object of our model. Learning by doing, for example, is responsible of a large amount of innovation able to improve products and processes. However, a large part of the technology innovation carried out by industries does not generates sensible competitive advantages and, by consequence, favorable socio-economic impacts in a territory. The reason is due to the fact that competitors react to technology improvements by developing their own improvements or other actions compensating the generated advantages in a situation that is called red queen regime. In fact to have real competitive advantages it is important that innovation should have some radical character needing new competences for its use that are not easily available to competitors. As discussed by R. Nelson and S. Winter (1977) and G. Dosi (1982) technological innovations may be divided in incremental and radical but only radical innovation may have a large socio-economic impact favoring extended technological development. In our model only technological innovations with some radical character are considered useful in a territory in terms of competitive advantages to its industry and favorable socio-economic impact to its population. The skew distribution of successful new technologies able to have large return of investment is a well known reality. In a statistical study carried out by F. Scherer and D. Harhoff (2000) on 1000 German patents hold valid in the first ten years of existence has shown that on 772 received answers only in five cases was indicated a very large return of investment. Data reported in this work show that only roughly 20% of patented innovations can be considered a real success.

Another important aspect of the model is financing of R&D projects. Currently most of R&D activity is financed by industry and public aid, however also venture capital may be of a certain importance. Industrial and venture capital are the two types of financing considered in the model and public aid is available for both. It does not seem existing a clear relation between industrial financing of R&D and generation of new technologies. Normally available industrial financing of R&D is reported in term of percentage of sales turnover, figures that are quite different following the various industrial sectors. Looking to R&D statistics, as published for example by the European Commission in reports (2003-2004) and (2008-2009), it appears a very limited growth of R&D expenditures respect to gross domestic product in most of highly industrialized countries. On the other side the amount of venture capital invested in R&D respect to the total R&D investments is ranging between 4% to 6% for the same countries (2002 data), and decreasing in European countries in the last years. For these reasons we have not considered any link in our model between successful technology innovations and industrial financing of R&D projects. In fact we have chosen two financing mode; one making available financing for all valid proposals of R&D projects and the other considering a plafond for available financing. In the case of venture capital there is normally a direct connection between successful innovations and available venture capital for R&D financing. Typically venture capital finances a certain number of innovations through R&D and start up activities up to industrialization level selling after the activity to recover an advantageous return of investment. Part of the return of investment is then reinvested in R&D activities. Venture capital is generally more effective than industrial capital in reaching a success for their developed technologies. That is due to the fact that venture capital invests rarely in feasibility studies making a more effective selection of R&D projects to be financed and much more coaching work than in the case of industrial financing. In Fig. 1 we have reported a schematic view of our model.

Implementation of the model and parameters used

Model calculations have been simply implemented using an EXCEL® sheet. A chosen number of R&D projects constitutes the initial input for R&D activity that proceeds in term of cycles. At the end of any cycle the number calculated of generated proposals is confronted with available financing to determine the new number of R&D projects in activity. This number may be limited following the case by availability of R&D financing or number of valid proposals. In the case of industrial financing this may be sufficient for all proposals or limited by a plafond. In the case of venture capital the available R&D financing is calculated through the number of successful new technologies, possible average return of investment and percentage of this reinvested in R&D. Considering the typical timing of R&D projects and development of new technologies, the cycle of the model may be assumed corresponding to about one year of activity and for this reason we have chosen to consider a maximum of ten cycles operating the model. Parameters and their correspondent values have been chosen as follows:

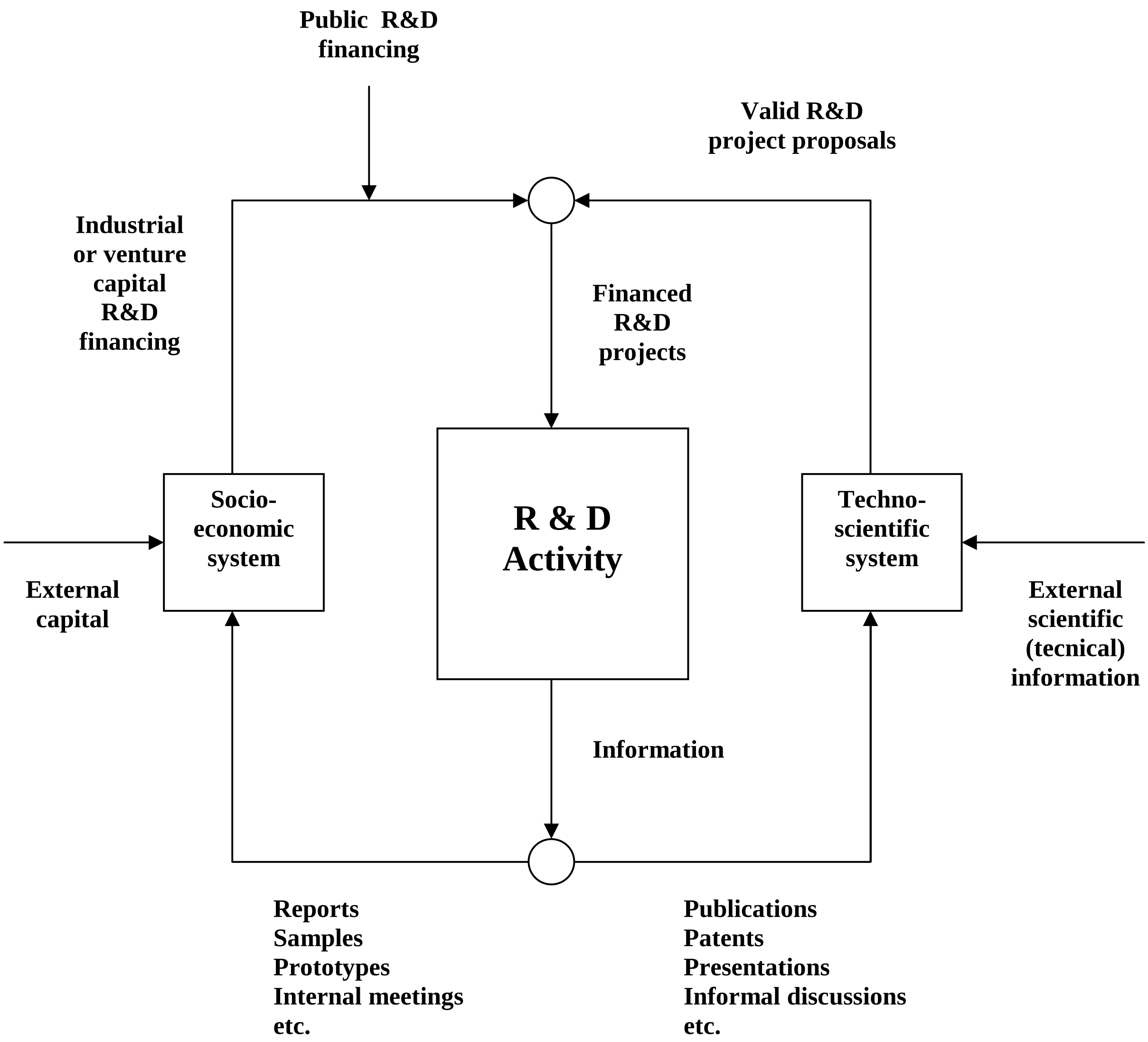

Fig. 1. Schematic view of the model of research & development activity

Generation of information for valid R&D proposals

As discussed previously combination of information coming from R&D projects activity is at the base of generation of new R&D proposals. It is then necessary for calculations to measure generated information and for that we have considered that information is available in form of packages. A project may generate several packages of information that combined with others may generate a new project proposals. Nature of the projects packages may be not necessarily technical but also marketing and even scientific. We have assumed for our model that on the average any R&D project carried out is a source of three packages of information. Scientific information, as we have discussed previously, also contributes to generation of new R&D projects especially when new phenomena or new aspects of known phenomena are available for conceiving new technologies. For our model is then important to estimate the packages contribute of science to the generation of new proposals. For this purpose we have considered the work of B. Latour (1987) that has studied structure and processes of techno-scientific system in industrialized countries. Following this author, using data published by the Scientific Indicator in the United States in 1982 and 1983, laboratory research constitutes about 11% of the total activity of the US techno-scientific system and development about 16% of the activity. The other activities are management of R&D, teaching and other activities including an important part constituted by administrative work in promoting, examining requests and supply money financing the functioning of the techno-scientific system. Following the cost data of the Scientific Indicator, basic research is about 7% of the total cost of research and development. Considering these figures we have hypothetically assumed that contribution of science in terms of packages of information useful for generating proposals might be about 10% of the information available from R&D projects, taking account that mapping contribution of science to R&D work has a limited value in term of generation of new ideas respect to knowledge of new phenomena. After definition of available number of information packages it is necessary to define the combination process that generate new proposals. Generally new ideas come often by combination of several packages from different projects and scientific information. In our model we have assumed that a new proposal is generated by combination of simply two packages of information either technical, marketing or scientific nature. Indicating with N the total number of packages available, the potential number of possible new proposal P is simply given by combinatory calculations as:

$$\mathbf{P = \tfrac{1}{2}N(N-1)}$$

that shows that number P of proposals is dependent on the power two of number of available packages. In fact only a limited part of potential combinations for proposals may be valid, many may be absurd and others inefficient. In every case the percentage of total valid proposals emerging from the total number of packages combination may be considered in a certain way as a measure of efficiency of the techno-scientific system to generate new proposals. The value of such percentage may then be variable depending of the territory with its specific techno-scientific system. In our model we have considered percentages varying from a maximum of 1% to a minimum of 0,01%. It should be noted that in our calculation we have considered proposals as generated only by packages coming from R&D project existing in a particular cycle increased by 10% of scientific contribution without taking account of initially existing packages and packages generated in previous cycles. Of course that is not in principle correct because any preexisting package may be useful for new proposals, however, considering that the model is applied to the case of territories starting with a very limited activity in R&D we consider that this used approximation does not influence practically the resulting qualitative behavior of the model.

Generation of new technologies and financing

Another important aspect of the model concerns the rate of generation of new technologies from the R&D projects and availability of financing for new R&D proposals. As discussed previously we are interested to innovations that have some radical character and that are able to support a real technological development in a territory. That makes the difference from work on simple incremental innovations useful only to maintain firms in the red queen regime. Innovations with radical character are generally the result of early stage, high risk technology projects such as are considered in a previously cited report (Branscombe et al. 2000). The ratio of generation of new radical technologies apt to industrialization is low and many projects are abandoned, especially in the phase of development after feasibility studies in which is sometime called the "Valley of death" of technology projects (Branscombe et al. 2000). The abandoning of a project is not necessarily a completely negative result in R&D as in reality information coming by abandoned project, when made available in the techno-scientific system, may be useful for new R&D proposals as well as those coming from successful projects. In the model we have distinguished two different rates controlling the generation of successful new technologies. The first one concerns the rate between the number of new technologies that are industrialized in respect to the number of R&D projects carried out, and the second one concerns the rate of success of industrialized technologies. For the value of the first rate we have assumed a percentage of 1% and for the second rate assumed a percentage of 20%. However, in the case of venture capital financing, the rate of success of industrialized innovations has been considered higher for the reasons already explained and used a percentage of 50%. Such parameter values have been established considering mainly discussions hold by industrialists, venture capitalists and researchers reported in the report cited previously (Branscombe et al. 2000) and in particular in the article of Scherer and Harhoff (2000). As reported previously we have not considered any relation between available industrial financing of new R&D proposals with number of successful new technologies considering the amount of available financing enough for all valid R&D proposals or limited by a plafond value. Average financing of R&D projects has been fixed to 100 account units. It has not been considered useful to give amounts in some real currency as we are interested in calculating the number of successful generated innovations needing only valid relative figures for capitals involved. In the case of venture capital the average return of capital of any successful new technology has been fixed to 2000 account units and 80% of that considered reinvested in new R&D projects. That means that 20% of return of capital is considered sufficient to reimburse R&D expenditures, cost of venture capital operations and wanted margins of benefit. Finally we have considered in the model that public aid to R&D is simply of the same amount of financing of both industry or venture capital.

Discussion of the results of the model

Before entering in discussion on the model results we want to emphasize we are well aware that our model is only a rough representation of a complex activity such as R&D is. Although many processes adopted by our model may represent the major ones existing in R&D, the generation of new ideas for valid R&D proposals may be much more complex than simple combination of two information packages from R&D projects and scientific activities. On the other side used rates of generation of industrialized innovations and success of new technologies are quite hypothetical although they may be right in term of order of magnitude. The same observations are valid for adopted venture capital mechanism of reinvesting in R&D. Nevertheless, we think that many qualitative aspects emerging from the results of the model have a certain interesting implications when considering the promotion activity of R&D with the aim to generate a real technology development in a territory.

We have considered at first the case of R&D financing by industrial capital introducing different numbers of initial R&D projects at various percentages of generation of R&D proposals by the combination process of the model. It is easy to observe that it is necessary to start with at least a minimum critical number of R&D projects to enable the techno-scientific system of the territory to generate a number of proposal at least equal to the number of the initial R&D projects. Should the number of initial projects be lower than the critical one, the generation of proposals will be lower than the initial number of projects and consequently the R&D activity will decrease with time to its extinction. The critical number of projects necessary to generate at least the same number of proposals is of course dependent on the chosen rate of generation of proposals and decrease with the increasing of this rate. In Fig. 2 curve A represents the variation of such critical number as a function of the chosen generation rate of proposals. Another critical number is represented by the initial number of R&D projects that is necessary to generate e sufficient number of financed R&D projects in the second cycle able to generate at least one successful new technology considering, of course, that all new R&D proposals are financed. The generation of new industrialized technologies in the model is only 1% of the total valid R&D financed proposals. The number of successful innovations are, in the case of industrial financing, 20% of the industrialized technologies. That means that you need, in the case of industrial financing, at least 500 proposals to obtain a successful new technology. On the other side you need a critical initial number R&D projects to generate such a minimum of 500 proposals and equivalent financed projects in the second cycle producing at least one successful new technology. Such initial number of R&D projects is of course a function of the rate of generation of new proposals and increase with the decreasing of this rate. The resulting critical number of initial R&D projects are reported in the curve B of Fig. 2. When the rate of emerging proposals from combinatory calculation is high, the critical number obtained is sensibly higher than the critical number of projects able to regenerate the same number of proposals. Decreasing the generation rate projects critical number increase, and at very low proposal generation rates the difference decreases and curve B joins practically curve A. Looking to the graphic of Fig. 2 curve A and curve B divide the space essentially in three regions which make possible some interesting issues. In fact, starting development in a territory with a techno-scientific structure able to support a certain rate of proposal generation and a chosen initial number of R&D projects, we may determine by these initial conditions if the territory would have a technological development, stagnation or decline. In fact, if the representative point is in the region above the curve B, we are in condition to generate enough proposals and successful new technologies to assure the technology development. If the representative point is in the region between the curves A and B there is the possibility to regenerate more proposals but the number of projects will be insufficient in a second cycle to generate successful new innovations with consequent stagnation of technology and instauration of a red queen regime. Finally if the representative point is below curve A we have a situation of decreasing number of proposals and new projects with a conditions of technology decline.

In the case of venture capital financing of R&D projects the situation is different as there is a relation between industrialized innovations, successful new technologies and available financing for new proposals. That makes possible a more than linear increase of successful technologies in a territory, however, the initial number of financed projects should be above the critical value to enable the starting of the development process as such process would be practically hampered should the generation rate of new valid proposals too low. In Fig. 3 we have reported the calculated number of successful new technologies as a function of the number of cycles run in the model for two values of proposal generation rate respectively of 1% and 0.1%. In both case we have used a number of 200 initial R&D projects. In the case of a rate of 0,01% this initial number of 200 projects is insufficient and development cannot start. As expected the number of successful innovations increases with the generation rate of proposal, however, it should be noted that in the first cycles, although there is an increment of available proposals, the control of the number of

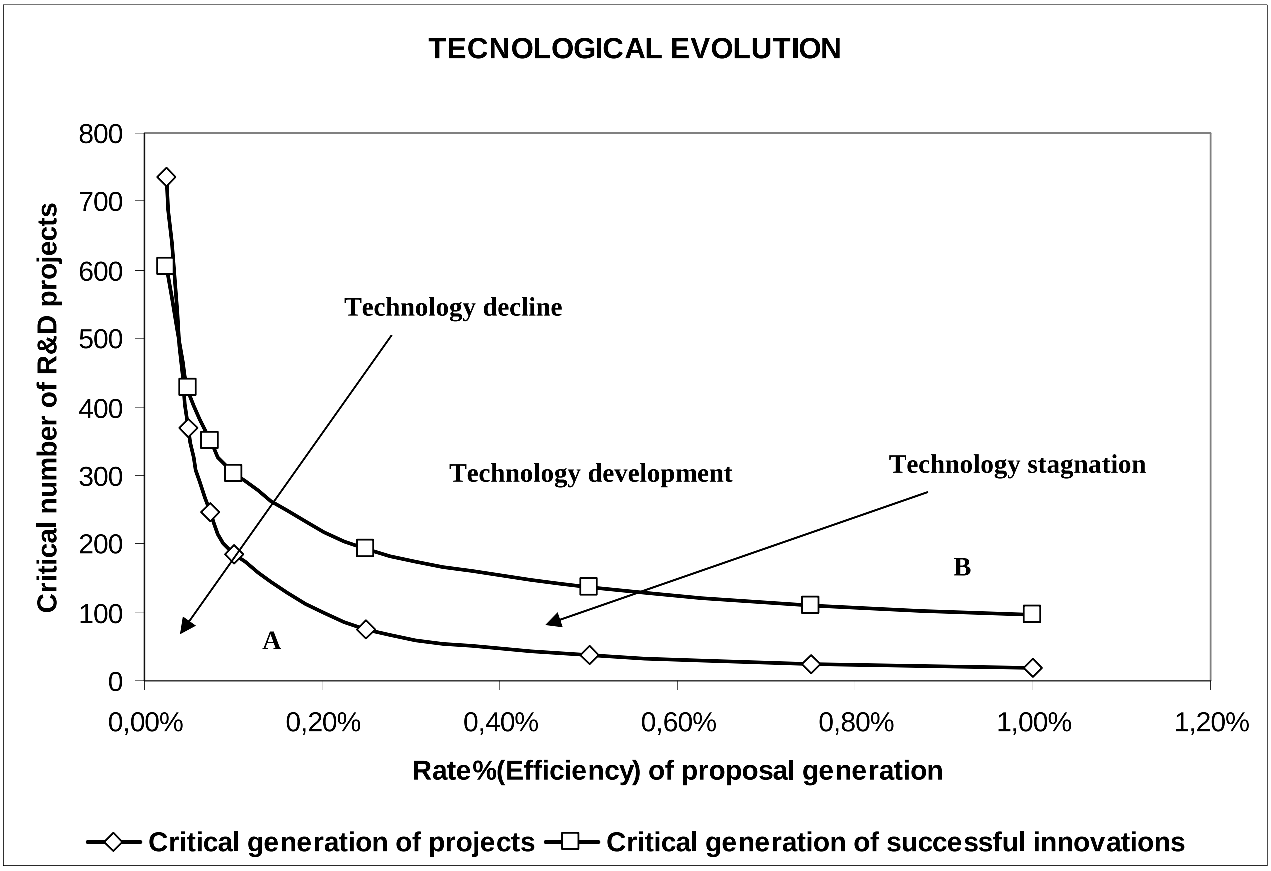

Fig. 2. Critical number of R&D projects as function of generation rate of proposals

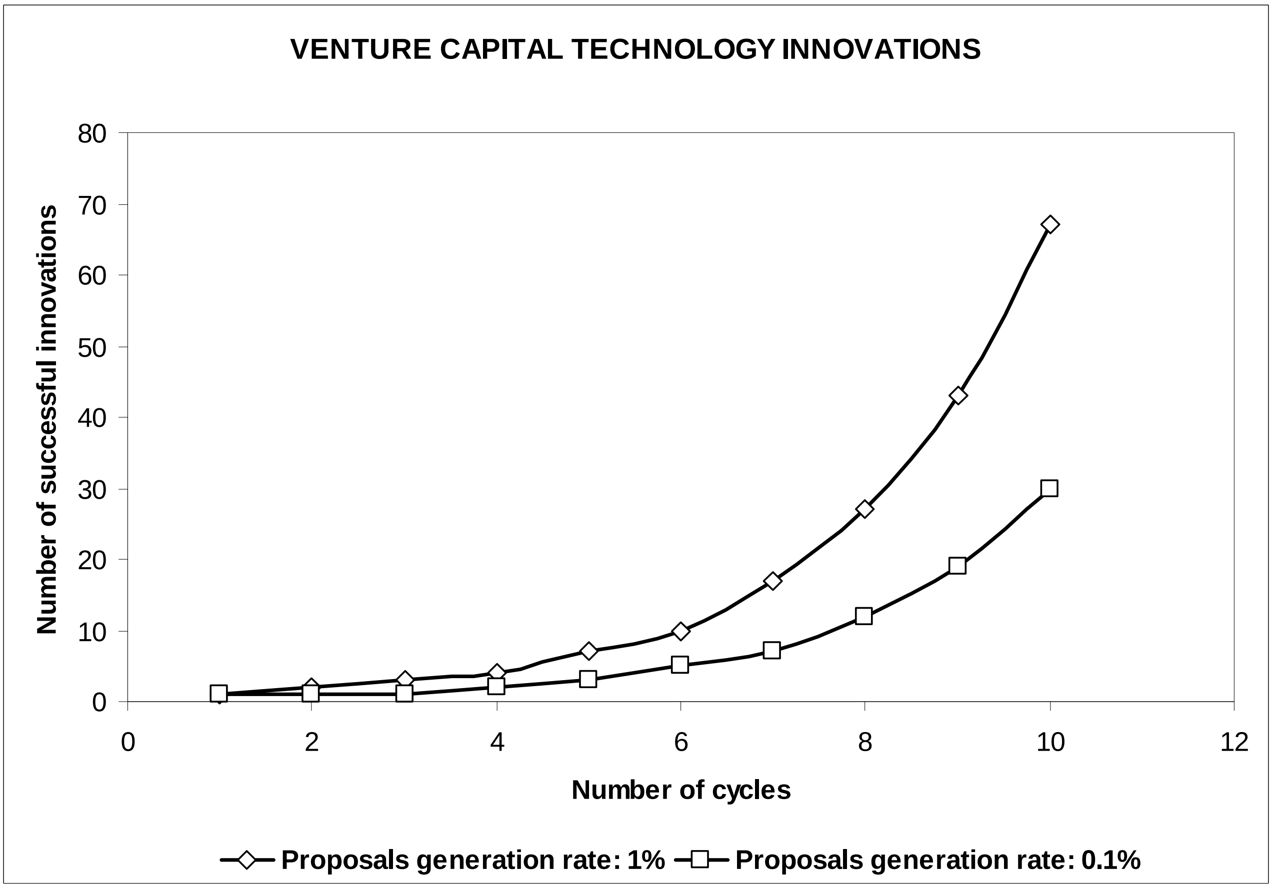

Fig. 3. Number of successful innovations as a function of number of cycle for two values of proposal generation rates

financed projects is exerted by the number of generated proposals and not by available venture capital financing as in the case of last cycles. In fact, lower is the proposal generation rate more cycles are necessary to reach a situation in which the number of financed projects is controlled by venture capital financing.

The first consideration appearing by running the model is the great importance of the process of generation of valid proposals in controlling and determining the technology development in a territory. This is in contrast with a very diffused idea that starting of technology development in a territory is essentially a problem of availability of capitals and public aids to finance R&D projects. This is particularly important for public policy which often offers aid simply making available funds for R&D without taking in consideration the techno-scientific system of the involved territory. This system may be too weak to trigger any real technology development and even after initial starting of a certain number of R&D projects there is only poor results in technology innovation.

Improvements of the model could be done for example introducing cumulative availability of information packages during cycling. That will of course increase the generation of proposals. We have not considered that in this preliminary development stage of the model as it would not change substantially the obtained qualitative behavior concerning the existence of critical number of initial projects determining situations of development, stagnation or decline of technology in a territory.

In conclusion, considering the results of the model, the promotion of technology development of a territory with a weak techno-scientific system should start with strengthening of this system in generating valid R&D proposals before making available capitals and funds for R&D projects. The structure of the techno-scientific system in a territory is composed by various organizations such as schools giving a technical and scientific educations, libraries with possibly access to technical and scientific data banks, research and technical testing laboratories, industries with internal R&D laboratories or at least people charged to follow technological innovation for the firm, industrial, educational, technical and scientific associations as well as other public organizations involved in innovation for the territory. All these organizations constitutes a network that should be favored by promoting a large exchange of information, organizing for example meetings and events but also promoting informal discussions among the various actors of such organizations. Furthermore, it could be also considered a direct approach to generate valid R&D proposals with specific territorial studies. This approach consists in a study based on cross fertilization of information coming from interviews carried out in the local industry and in research laboratories combined with information from technical and scientific literature and data banks. The aim of the study is in fact the identification of valid proposals for R&D projects interesting the territory. A successful case of application of this approach is reported in a paper (A. Bonomi, P. Marenco 2006) describing the promotion work done in Italy in the territories of the provinces of Novara and Brescia in the industrial districts producing taps and valves. In such case a first study produced a series of proposals and one of these made possible the creation of a R&D company financed by six firms of the sector on development of a technology eliminating contamination of drinking water with lead contained in the brass used for taps and valves. A second study later made possible the generation of various R&D proposals making possible the creation of a cooperative organization, constituted by more than twenty firms of this industrial sector, dedicated to development and management of R&D projects.

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