Generation of R&D Activity and Implications in Technology Development of a Territory

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1. Introduction

The influence of technology on growth has been demonstrated since the classic 1957 article by Robert Solow revolutionizing the production theory. Solow's basic conclusions were widely accepted but certain aspect of his model were criticized being technology considered primarily labor-augmenting but might be also capital-augmenting (Jorgenson 1966). Another issue was that Solow treated technology as exogenous, more depending on the level of science, but in fact technical advance may be endogenous and dependent on investments in R&D or human capital (Romer 1990, 1993). For this reason there has been considerable work on correlating productivity to observed measures of technology such as patents or R&D (Griliches 1984, 1998). More recently an outstanding summary of the literature on R&D has been provided (Hall et al. 2009) showing positive rate of return to R&D in many industrialized countries and that government-funded R&D is less productive than private R&D. When you want apply statistical approaches in measuring returns to R&D in small industrialized territories existing in a country, the stochastic nature of R&D outcomes and the fact that technology innovation is also resulting by learning by doing activities, not registered as R&D investments, prevent the availability of reliable statistical data. In order to avoid statistics in studying influence of technology innovation on socio-economic development of a territory, we have developed a completely different approach based on the nature of processes characterizing R&D and considering estimated rates for generation of a certain number of successful new technologies as a measure of return to R&D activity existing in a territory, and, indirectly, of its economic and social growth. Calculation of number of successful new technologies has been carried out using a simple model simulating in general an R&D activity. Such model is the results of a long period, more than 15 years, of empirical observations on technology innovation processes existing in small and medium enterprises (SMEs), especially when organized as industrial districts. In fact in this study we consider the case of territories with a large presence of SMEs, often organized as industrial districts, and characterized by a major use of conventional technologies, high rates of export, and facing increased global competition. Such industrial situations may be found for example in many territories in Italy. We will discuss in this paper which type of technology innovations are the most suitable for such territories, in order to make their SMEs more competitive in the medium and long term, and which are the main factors influencing the generation of new successful technologies. For this purpose the study considers the existence in a territory of a socio-economic and a techno-scientific system interacting in the generation of new technologies and that interaction can be simulated by a simple model of R&D activity developed in this study. The quantitative results obtained by the model raise a certain number of implications useful in suggesting improvements in promotion of technology innovation or contrasting decline in past highly industrialized regions. After this introduction in a second chapter we discuss about nature of technology, types of activities leading to technological innovations and about innovations in term of their radical degree and consequent impacts on development of a territory. In the third chapter we present the model of the R&D activity and its dynamic in a territory. In the fourth chapter we discuss the quantitative aspects of the model and choice of parameters and corresponding values. In the fifth chapter we present the results of the model about influence of efficiency of generation of R&D activities in respect to generation of new successful technologies. In the sixth chapter we discuss the results of the model showing the non linear dependence of number of R&D projects and corresponding financing on the number of obtained successful new technologies. This number is found related to the existence of critical values of level of R&D activities. Above these values there is technological development and below these ones decline. In the seventh chapter we discuss implication of results of the model about optimization of public aid to promotion of technological innovations and in the eighth chapter we present the conclusions obtained by this work.

2. Technology and technology innovation

Before entering in discussion about generation of R&D activity following our model it is useful to present some considerations about the nature of technology, the activities leading to technology innovations and the various types of technology innovations with their different impacts on development of a territory.

Nature of technology

An important definition of technology assumes that it is a means to fulfill a human purpose and that its evolution has a combinatory character and past technologies have an important role in generating new technologies (Arthur 2009). Laser is an example of a new technology resulting by combination of known electronic device technologies becoming able to capture and exploit a new phenomenon of emission of coherent electromagnetic waves (Arthur 2009). Adopting such point of view we may easily consider that results of R&D activities, independently to the fact they lead or not to successful new technologies, are a basic source of knowledge for combinatory processes generating innovative ideas for further new technologies. Considering now the R&D activity existing in a territory, the level of such activity would play by consequence an important role in generating more or less new R&D activity as a function of the potential combinatory process emerging by obtained R&D results. Now, if we exclude the import of new technologies or R&D projects in the territory, an internal high R&D activity would generate a high number of R&D projects and consequent high number of new successful technologies, while a low R&D activity would generate only a limited number of R&D projects resulting in a poor number or absence of new successful technologies. The result for the territory would be development in the first case and stagnation and decline in the second one. Concluding self generation of R&D activities would play an important role in understanding the dynamic of technology innovation in a territory.

Technology innovation activity

For our purposes it is important to define the various types of activities leading to technology innovations. Such activities may be classified in two fundamental types: learning by doing (LbyD) and research & development (R&D) and each type results in a different impact on future development of a territory. In the case of learning by doing we consider the original definition (Arrow 1962) in term of shop floor work increasing manufacturing experience leading to a positive macroeconomic production externality independently of bringing additional capital or work and even R&D investments. Beside shop innovative work we may include in LbyD also introduction of new existing technologies, adaptation of technologies existing in other industrial sectors, testing and analytical work in external laboratories and even support by experiments in research laboratories. Such type of activity is typically used by SMEs to carry out technology innovation and explains for example the observed paradox in Italian SMEs industry in which its acknowledged high technology level is accompanied by low registered investments in R&D. In fact LbyD is not generally accounted separately in SMEs but its costs are generally included in maintenance, production or general investments costs. Research & development is the other type of activity leading to technological innovation and it is characterized by work in research laboratories rather than on shop floor, generally in form of specific research projects in a sequence of steps, developing innovation from an initial innovative concept to its industrialization. The various steps involved in development of a technology innovation through R&D may be included in three main important phases that are:

- *Feasibility phase* in which the technological feasibility of the innovative idea is verified
- *Development phase* in which performances and specifications of innovation are considered as well as costs and economy of innovation. That may include also work on pilot plants or realization of prototypes.
- *Industrialization phase* composed mainly by design and planning work for an industrial use of the innovation

It should be noted that R&D work, differently or in a much larger extent than in LbyD, is generally accompanied by state of the art, market and patent studies that may be carried out even before experimental work and throughout the various phases of development. Considering technology innovation as a process of change of technology, both LbyD and R&D are basically the same process, although using different means, but changes in R&D are generally more important than in LbyD and consequently patent production in R&D is more important and type of produced innovations may be different and different the impacts on the economy of a territory.

Technology innovation type

Technology innovations may be classified in term of incremental or radical ones (Nelson, Winter 1977) in which radical innovations are considered a discontinuity in the trajectory evolution of a technology (Dosi 1982). For our purpose it is interesting to consider not simply the fact an innovation could be incremental or radical but have also an idea about its radical degree. For such evaluation it is necessary to consider a technology as a structured set of technological operations each characterized by a certain number of functioning parameters. For example a technology of thermal treatment may be constituted by operations of heating, maintaining at a certain temperature and cooling and parameters may be the heating velocity, the maintaining time and temperature and the velocity of cooling, etc. (Auerswald et al. 1988). An incremental innovation may be simply characterized by an optimization of parameters and possibly substitution of a limited number of operations. A radical innovation may instead include a large substitution of operations in the structure of the technology. The extent of changes in operations constituting a new technology may be seen as a measure of the radical degree of this technology (Bonomi, Riu, Marchisio 2007). For example, in the substitution of the old typewriting machine with the radical new technology based on computer/printer system only the QWERTY distribution of buttons in the keyboard is conserved. Typically incremental innovations may be obtained by LbyD while radical innovations may require, although not exclusively, R&D work. When the change of a technology involves a large number of new technological operations, it is very possible that the firm adopting the new technology does not have at the beginning the necessary competences for certain operations. These competences may be acquired through the development work or transfer of technology. Consequently, while incremental innovation may be achieved in the frame of competences existing in the firm, the implementing of radical innovations may require quite new different competences. Although the greatest part of technology innovations is incremental, such type of innovation is not really useful to create development but rather to assure the survival of the firm in a world of continuing innovation of technology. Only innovations with a certain radical degree are able to generate durable competitiveness and development. Such situation may be easily explained considering that: when a firm develops an incremental innovation in the frame of available internal competences, also competitor firms having the same competences may develop a similar alternative technology destroying competitiveness of the former innovation worsened by the fact that incremental innovation cannot generally produce a strong patent position. In the case of radical innovations competitors do not have easy available competences to counter the innovation and may be prevented by strong patent positions. The consequence is a more durable competitiveness and development of firms concerned by innovations with a high radical degree. A strategy based only on incremental innovations, as often observed in traditional SMEs, is currently valid to maintain a good technological position but may present future threads in the globalization of productions. In fact firms of emerging countries acquire with time substantially a similar technological level reaching a situation in which other advantages existing in these countries summed to acceptable technology efficiency make such countries very competitive with dangerous consequences to traditional producers. Concluding, the real arrest of decline and assuring the development of a territory would depend more by R&D activity than by LbyD and by realization of technological innovations with a certain radical character.

3. A model of R&D activity in a territory

Assuming the importance of R&D activity in the development of a territory, in order to describe its dynamic, it is useful to develop a model of this activity. For this purpose we have taken in consideration a model presenting the complex input and output existing in the R&D activity of a single firm (Dumbleton 1986). We have extended this model to the entire activity of a territory comprising various types of industries, mainly SMEs, without owns research laboratories, in which R&D is carried out mainly by contract research and in which big industries are absent or existent in so limited number that we may consider the majority of territorial R&D activity carried out externally in what we may call an open (Chesbourgh 2003) or distributed (Haour 2004) innovation system. The basic idea of our model is that R&D activity is generated by the existence of a financial flux supporting a certain number of R&D projects. Such financial flux may be composed by various type of industrial, venture, etc. capitals, possibly combined with public aid, and coming from the socio-economic system of the territory. On the other side the flux of valid research proposals for projects is generated by what it may be called the techno-scientific system of the territory. Both the socio-economic and the techno-scientific systems have external relations exchanging respectively capitals and scientific and technical knowledge. The results of R&D activities may be confidential such as reports, samples, processes, meetings, etc. that are available to the socio-economic system to decide the industrialization of a new technology. Other results are open to public such presentations, patents, publications, etc. and may be used by the techno-scientific system to generate new proposals for R&D projects. The nature of results of R&D activity is essentially information. Tacit knowledge or know how developed during the R&D activity is negligible in term of usability as know how developed during the various phases of R&D is different by know how necessary to exploit industrially a technology. Public information, accompanied often by informal discussions, is essential to generation of new ideas in the techno-scientific system. In Fig.1 we have reported a schematic view of the model presenting the various fluxes of information and financing related to the R&D activities and involving the socio-economic and techno-scientific systems. As our study concerns the generation of R&D activity, we do not enter in describing details of the socio-economic system of the territory and its activity in financing industrialization of new technologies and R&D. The techno-scientific system is composed by various actors that contribute to promotion of technology innovation, carrying out of R&D activity and exploitation of the generated new technology. The main actor of a territorial techno-scientific system is of course its industry as source of projects, financing and exploiting of new technologies. However not all firms are active in the same way. Generally the industrial structure of a territory is composed by a great number of small firms that in fact are not active in generation of new technologies but only possibly users. In our considered territories, great industries are absent or present in a few number and may depend on multinational groups in which R&D is not necessarily carried out in the facilities of the territory but far away. The presence of great industries may be accompanied however by a certain number of smaller subcontracting firms, depending on technology of such industries and corresponding technology developments. The most involved firms of a techno-scientific system are the new technology based firms (NTBF) and conventional technology based firms (CTBF), these last generally characterized by high rate of export and competition in the global markets in terms of products and technologies. NTBF are normally linked directly to R&D activities but are generally present in a few number on the territory. CTBF have a major importance but they are more active in LbyD than in R&D for technological innovations. Although NTBF may generate in future positive impacts to the territory, CTBF are generally more important constituting a critical industry for the future economic sustainability of the territory. Other important actors of the techno-scientific system are laboratories carrying out R&D as separate entities in contract research organization or in universities and technical secondary or high schools with the task to diffuse a technical and scientific education. Other important actors are organizations and structures for the promotion of technology innovation. Organizations are for example territorial or sector industrial associations, chambers of commerce etc. and structures, scientific and technological parks, incubators, etc. Finally we may consider in the system also testing and analytical laboratories that may be of support to LbyD and in certain cases also to R&D. In determining the efficiency of the techno-scientific system internal relations among the various actors of the territory and their external relations may be more important than the actors themselves. The R&D activity, as we have previously noted, is composed by R&D projects in different phases of development presented previously. Actually, financial support and even innovative contributions from the techno-scientific system may involve all steps of R&D. In fact the model, considers only an initial financing support to projects making a simplification of the reality but that we consider acceptable for our discussions on R&D activity.

Considering now the dynamic of the model we observe that the limits to the R&D activity may be either the financial support or the availability of valid R&D proposals. A bottleneck may arise when an efficient techno-scientific system generates a high number of valid R&D proposals but there is not enough financing for all projects. On the other side a bottleneck may arise also when there is a less efficient techno-scientific system generating a few number of R&D proposals in presence of a good availability of financing. In the first case the limits of R&D activity depends on the socio-economic system and possibly public aid and may be the consequence of chosen industrial strategies, economic difficulties, low propensity to risks, etc. As the purpose of this work concerns generation processes of R&D we do not enter in more details concerning the socio-economic system and put our attention to the other case in which the limits to R&D activities are the number of proposals, situation existing especially in territories with scarce development and declining industries. The generation process of valid R&D proposals is based on information generated by the R&D activity. That means, as experience suggests, that either successful or abandoned projects are a major source of useful information for future R&D projects in a territory. About the process of formation of innovative ideas for R&D proposals, it should be considered that technology innovation has a combinatory origin (Arthur 2009). The number of overall potential new ideas for innovation will then increase with the amount carried out R&D in a non linear way following a growth based on combinatory rules. Information coming from R&D activity is combined also with external sources concerning scientific and technological knowledge and the number of valid R&D proposals will be a function of efficiency of the techno-scientific system in these combinatory processes. Typical sources of technological innovations are industries and contract or university research laboratories but also the other actors of the techno-scientific system may contribute supplying useful information to the generative processes. As the number of R&D proposals is a function of available information, there is with time an accumulation of information for R&D but at the same time a fading effect and loss of some information. Although past information may be less useful than recent one, reduction of fading effect by conserving past information as much as possible is anyway favorable to the efficiency of the techno-scientific system.

It is well known by experience that only a minor part of R&D projects becomes successfully new technologies with positive impact on the territory. That means that if R&D activity in a territory is low there is a situation in which statistically few or none successfully new technologies are generated with a consequent stagnation of technology developments and industrial decline. When a certain number of R&D projects are financed, there are two possible situations. In the case of an efficient techno-scientific system there is generation of R&D proposals in an even greater number than starting number of R&D projects by the combinatory effect of generated information boosting technology development for the territory. On the contrary, in the case of a techno-scientific system with low efficiency, a lower number of R&D proposals will be generated, causing a decreasing number of R&D proposals and consequent technology stagnation and decline. These dynamics imply that simple financial efforts of investment in a territory may be inefficient to improve industrial development by R&D if its techno-scientific system is weak, and financial efforts would be more effective when they are previously addressed to enforcing the territorial techno-scientific system than simply supporting R&D projects.

4. Quantitative aspects of the model

In order to have a better knowledge of relations among the various aspects of the model it will be useful to study quantitatively the dynamic. Actually the R&D activity is too complex for the realization of a fully realistic quantitative model enabling even forecasting. However, it is possible to realize a simplified model simulating such activity, without claiming forecasting possibilities, but able to give useful indications about the effects of R&D activity in a territory. Such simplified model requires for its construction a certain number of approximations and acceptable simulations of processes that will be explained as follows with the respective justifications. The first important simulation concerns the fact that R&D activity is practically a continuous process of financing valid R&D proposals and starting and ending of new projects. In our model we have simulated for simplification such continuous process using a sequence of cycles. Each cycle starts with a certain number of financed valid R&D proposals generating, through R&D activity, a selected number of industrialized technology innovations that would be or not successful in assuring a positive socio-economic impact on the territory. Information coming from R&D activity is available to the techno-scientific system to generate new valid R&D proposals restarting a new cycle. As we limit our interest to R&D generation, we consider in model dynamic that there is always enough financial means to support all the generated valid R&D proposals. Cycle time is not defined quantitatively in our model but it is of course in relation with average duration of R&D projects until industrialization of innovations and in the order of magnitude of few years. Concerning approximations, the model should face the fact that many of parameters that should be used are not available from statistical studies but may be only estimated approximately through considerations based on experience in R&D field. For example, considering the selection process starting from innovative ideas to successful new technologies, a statistically representative sample of projects would be probably so large and information difficult to obtain, that makes practically impossible a statistical study. Some indications about selection processes in R&D activity may be obtained considering a study carried out on 1000 German patents hold valid for at least 10 years (Scherer 2000). This work has shown that only 5-10% of patents have originated a large return of investments and only about 20% can be considered really profitable with returns from R&D investments that are observed skew distributed among the patents. Now you should take account that history of this studied group of patents may be accompanied at the same time by a certain number of patents that have been abandoned by loss of interest or validity after litigations, as well by a certain number of R&D projects unable to produce valuable patents. That corresponds to a huge number of projects from which are derived the more or less successful patents identified in this study. These considerations, and the experience in R&D, suggest us that a ratio of three orders of magnitude between number of valid proposals and successful new technologies may be a reasonable and realistic estimation. The huge dimension of a statistically representative sample of R&D projects makes that in a territory of necessary limited dimension never exists such elevated number and results in the reality have a more or less stochastic origin. This is of course a limitation of our model in term of forecasting but not necessarily for studying relations between the various parameters of the model. A further aspect of evolution of an initial number of R&D projects concerns the fact that the rate of discontinuation of projects is different following the three different phase of development cited previously. Such situation is reported schematically in Fig. 2. In such representation, in absence of availability of real statistical data, we have neither given precise figure of time, that in every case it is in term of years, nor of residual number of existing projects, that would be represented on a logarithmic scale. We consider however such representation a good indication of what it is really occurring in the evolution of the number of projects. We may observe that, on the contrary of what generally might be thought, it is the development phase, instead of the feasibility phase, to have the greatest rate of discontinuation of projects, while industrialization phase has, as expected, the lower rate. Such fact is well supported by experience and development phase is considered in fact the "Valley of Death" of R&D projects (Branscombe 2000). In order to study by the model how the efficiency of the techno-scientific system influences the generation of valid R&D proposals, and finally successful new technologies, we should consider further parameters for the model concerning generation of information, rate of generation of valid R&D proposals, rate of selection of innovations for industrialization and rate of success of industrialized innovations. Their quantitative values, with the justifications of adopted approximations and simulations, are discussed in the following points:

Generation of information

As discussed previously, R&D activity is the basic source of information for generation of innovative ideas and finally new valid R&D proposals. The model considers public information the major source of new ideas, however it is true that confidential information has also an important role in industries having their own R&D activity and even contract research organizations may have useful confidential information coming from their activity with industries, however, open information is considered in the model the major type of information available in the techno-scientific system for such purpose. In every case we consider that projects are the direct source of exploitable information, independently they are successful for industrialization or not as discussed previously. Following the combinatory nature of generation of innovation, it is necessary to quantify information coming from projects in term of number of available packages. For model calculations we have assumed that each project generates an average of three packages of information, value in a certain way arbitrary, but coherent with feelings by experience in R&D concerning the birth of new innovative ideas by various sources. That means the total number of packages will be three times the number of projects. It should be noted that packages are not necessarily of technical nature but may be for example also marketing information or other coming from studies carried out in the frame of R&D projects beside the experimental activity. We assume that in the greatest number of case a new potential idea is born by combination of two available packages allowing in this way calculation of number of potential proposals generated by R&D. Indicating with N the number of packages, i.e. three times the number of projects, the number of potential new proposals P will result by combinatory formula:

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

In which the number P of potential proposals is a function of power two of the number of packages, and then of number of projects, well showing the non linearity of the number of potential innovative ideas as a function of the number of projects. We have however to consider also that the techno-scientific system has external exchanges of scientific and technical information that may also contribute to the generation of proposals and in our model we have supposed that external additional contribution to the number of potential proposals is ten percent of the number of proposals P obtained by R&D. As in the case of number of generated packages by projects, such figure is in a certain way arbitrary but coherent with experience in R&D cited previously. Another aspect that should be considered in generation of information packages is the existence of a fading effect on availability of packages of information cumulating with the increase of time i.e. the number of cycles in the model. For the calculation made with the model we have chosen two scenarios: the first considers that only information packages coming from the previous cycle are available, the other one considers that also the other past cycles contribute with a fading effect of reduction of information of 50% at each cycle calculation.

Efficiency of the techno-scientific system

Most of the generated potential proposals by a pure combinatory process of packages will be absurd or without interest, the efficiency of the techno-scientific system is represented by its ability to identify a certain number of valid combinations i.e. valid R&D proposals and may be expressed in term of percentage of the total number of available combinations increased by 10% to take account of arriving of external information. In our model the efficiency of the techno-scientific system will be studied as a variable parameter generating successful new technologies. For this purpose we have chosen a range of efficiency between 0.01% and 1% of total potential combinations available for proposals generation coherently with achievable successful innovations for the territory.

Efficiency of the R&D activity

During the R&D activity projects are selected in view of a further industrialization. Efficiency of such selection depends on many factors. A R&D project is at the beginning accompanied by a certain degree of incertitude about its success. For incertitude we intend the fact that it is impossible to establish a probability about its risk of failure (Knight 1921). That means that there is in each project an intrinsic risk of failure that it is independent by efficiency on how R&D is carried out. In a certain way the R&D activity allows the transformation of incertitude into risk clearing the probability of success or failure and making a decision to continue or not a project. It should be noted consequently that financial efficiency of an R&D project is not determined by its success but by minimization of the financial effort necessary to transform incertitude into risk. This is coherent with the fact, as reported in Fig. 2, that the majority of initiated R&D projects will be abandoned with financial loss of R&D investments. On the other side a good practice of the R&D activity will allow the advancement of projects without intrinsic risk of failure, but with the risk to be abandoned by other reasons including failure by R&D in showing their validity. In conclusion the rate of selection of projects during the R&D activity usable in the model will depend on many factors such as intrinsic risk of failure, inadequate R&D practice and interruption of financial support due to perception of a high risk. For an estimation of rate of selection we have considered the value of 1% of survival of projects in respect to the amount of valid proposals feeding the R&D activity. As in many other cases such figure is not resulting from statistical studies, but it is coherent with experience in R&D as discussed previously presenting Fig. 2.

Rate of success of new technologies

In our model the rate of success of new technologies is represented by the ratio between the number of technologies that are used industrially with a good return of investment in respect to all the new technologies that are industrialized. It is expected that such technologies have a certain radical character and adequate positive socio-economic impact on the territory. We have considered for the model that 20% of the total industrialized technologies reach such objectives coherently with information about rate of success of new enterprises, start up etc. and indirectly by data concerning success degree of patents (Scherer 2000). It should be noted that, choosing the given values of rates of selection of R&D projects and of success of industrialized technologies, it means that, by combination of the two rates, it is necessary a total of 500 R&D projects in our model to generate statistically one important successful new technology. Such figure may appear exceeding great, however, it should be considered our strict definition of successful technology that are limited in number in respect to the numerous used new technologies. In fact, many new technologies resulting by R&D projects are industrialized with little return of investment and useful just to maintain an adequate technology level in respect to competitors, or even just slacking decline. Such innovations have actually a negligible effect on the socio-economic development of the territory.

5. Results of the model

Before entering in presentation of results of calculations with the model, we would stress the fact that this model is not a real reproduction of the complex activity of R&D, but only a simulation unable of course to make predictions but useful to draw attention, also by a quantitative point of view, to relations among the various factors that influence R&D. We are also well aware that most of parameters values used by the model are in a certain way arbitrary, but not unreasonable for the purpose of the model, and probably realistic at least in term of order of magnitude. Model calculations have been simply implemented using an EXCEL® sheet. The calculation starts with the number of R&D projects existing in a cycle and determining the generated number of information packages (three in average per project). The number of obtained potential innovations is calculated with the formula reported previously considering all possible combinations of two packages, and increased of 10% to take account of external information. The number of generated valid R&D proposals is calculated as a function of the rate of efficiency of the techno-scientific system taking account of the whole number of potential innovations. As we consider in this study that financial support is always available for all the valid R&D proposals, their number will be equivalent to the number of R&D projects entering in activity in the subsequent cycle. From the number of R&D projects it can be calculated the number of industrialized projects following the rate of efficiency of R&D activity, and from the number of industrialized projects the number of successful new technologies using the established rate of success. In order to study the influence of efficiency of the techno-scientific system in obtaining successful new technologies, we have imagined to supply to the system in a first cycle a certain number of R&D projects to implement its activity, in a range of few tenths to several hundreds projects, and calculating the number of valid R&D proposals generated by the techno-scientific system and available for a second cycle. There are various possible scenarios. Should the efficiency of the techno-scientific system be very low, the number of generated valid proposals will be lower than number of initial R&D projects, and the system will decrease more and more the future R&D activity in condition of technology stagnation or even decline. In the case of an efficient techno-scientific system the number of generated valid R&D proposals will be higher than the number of initial R&D projects and increase with the number of cycles. It is possible, with a very efficient techno-scientific system, or high number of initial projects, to reach already in the second cycle a number of valid proposals, i.e. R&D projects, sufficient to obtain statistically at least one successful new technology. In every case we have considered the system in condition of technology development when such critical number of R&D projects generating at least one successful new technology is reached after a maximum of five cycles. In the first run of calculation we have considered that only the information available by the previous cycle is useful to generate new valid R&D proposals. That means that there is a 100% fading effect and loss of all information coming from past cycles. In Fig. 3 we have reported the critical number of starting R&D projects able to generate at least one successful new technology as a function of efficiency of the techno-scientific system of the territory. All points with coordinates below the represented critical curve correspond to conditions in which there is no generation of any successful new technology in a situation of stagnation and decline for the territory. On the contrary, points with coordinates above the critical curve correspond to statistical generation of at least one successful innovation and a situation of technological development and positive socio-economic impact on the territory. It should be noted that in the case of an inefficient techno-scientific system a successful new technology can be generated only by huge number of initial projects that may be unseasonable to consider for a territory. In a second run of calculation we have taken account of a fading effect on information of 50%. That means that past information cumulates for calculations but it is halved at each new cycle. In Fig. 4 we have reported a comparison between the two situations with 100% and 50% of fading effect showing how it is important conservation of information in reducing the starting number of R&D projects necessary to trigger a successful new technology at a given efficiency of the techno-scientific system of the territory.

6. Discussion of the results

Considering the results of the model it appears clearly that number of valid R&D proposals may be a bottleneck for R&D activity in a territory, and showing that, contrary to a diffused idea, availability of even a large financial support may be not sufficient to trigger technological development when the efficiency of the techno-scientific system is too low and, as told previously, a financial support will be more effective when addressed to the enforcing of such system. In fact the quantitative results of the model show that the number of successful new technologies are not simply proportional to the number of R&D projects or amount of financing support. Furthermore there is a critical level of R&D activity that should be reached to have statistically a probability to realize at least one successful new technology, otherwise the efforts will be without effect. Although critical figures given by the model are only indicative, it is reasonable to consider, by previously discussion on rate of success of R&D projects, that it is not easy to reach in a territory the critical number of projects assumed by the model assuring the statistical generation of new successful technologies. For these reasons technology development in a territory cannot be obtained simply in increasing the number of projects, as in a typical portfolio strategy used to manage risk in financial investments, and it would be more effective the increasing of the system efficiency by accurate selection of projects that should be industrialized, and effective coaching of projects under development. Concluding, overcoming of low probability and skew returns in generating new successful technologies could be contrasted, not only by increasing number of financed valid R&D proposals by an efficient techno-scientific system of a territory, but also by a good practice in R&D activity, effective coaching of projects, and a good selection of technologies that should be industrialized. Public aid may also influence the generation of new successful technologies and considerations derived by implications coming from the results of the model are reported in the following chapter.

7. Promotion of technology development by public aid

One of the tasks of public aid to industry is reduction of financial risks in developing new technologies by sharing costs of R&D. Efficiency of such task will depend on adopted rules of public interventions in the various phases of R&D activity. As we have discussed previously, new R&D projects are accompanied by a large incertitude about their success and R&D work transforms incertitude into risk, or assessed probability to succeed, supporting decisions to continue or not a project. There exist various types of incertitude or risk accompanying an R&D project (Scherer 1999) each ones reduced in different way during the various phases of R&D activity as follows:

- *Technical risk*: incertitude of such risk drops rapidly already at the end of the feasibility phase
- *Performance risk*: its incertitude consists in obtaining a suitable level of performance and in reaching required specifications for innovation and drops generally in the development phase

- *Cost risk*: its incertitude concerns assessing the economy of the innovation and drops also in the development phase, normally after the performance one.
- *Market risk*: this is the risk associated generally with a major incertitude that, although market studies can start even during the feasibility phase and continue during development, it drops really only after industrialization of innovation

Evolution of risk incertitude during development is important in considering at which phase a public aid will be more effective. In fact there are two specific moments with a particular need of help justified by different reasons. During the development phase there is a moment in which continuation of the project requires a strong increase of investments but in which the incertitude of the various risks remains still high, for example when research should continue through construction of pilot plants or prototypes or creation of start up. This moment is normally present in an advanced phase of development. Another critical moment in R&D activity concerns the generation of valid R&D proposals at beginning of R&D activity of the feasibility phase. As shown by the model, at this point we need a large number of valid proposals and at a same time a valid selection of projects in order to favor generation of successful new technologies. In fact, incertitude on the destiny of a R&D project is at a maximum at beginning of R&D activity, while the reliability of selection that should be made, because of the high incertitude, is at this moment at a minimum. An interesting possibility to overcome this difficulty is in accompanying selection of projects by prefeasibility studies on a large number of innovative ideas financed by available public aid. In such way actors of the techno-scientific system, in particular universities and laboratories for contract research may select and improve valid proposals making them more attractive for financing by industries and even by SMEs. In fact, feasibility phases have generally a minor cost affordable by a SME, especially when it could further count on access to help in the most critical phases of development as cited previously. Public aid, organized in this way, may boost R&D activity in a territory, and in particular contract research organizations that may develop an active proposals attitude to industry, playing an important role as an effective bridge between research and business. For these reasons creation of contract research organizations should be favored for example as spin off of universities as separate entities. Finally, other important problems existing for SMEs in carrying out R&D activities are lack of financial and human resource for R&D projects (Bonomi Haour 1993), but these problems could be in many cases solved by cooperation (Bonomi Rolfo 2012).

8. Conclusions

This study has shown the importance of R&D activities for socio-economic development in territories with an industrial structure composed by SMEs with conventional productions and facing global competition. It has been shown the importance of an efficient techno-scientific system of a territory in determining its technological decline or development. Generation of competitive new technologies with positive socio-economic impacts has been considered possible rather by R&D activities for innovations with a certain radical character than by LbyD activities with mainly incremental innovations. Starting from the fact that technological innovations are the results of a combinatory process depending essentially by past R&D and import of scientific and technical knowledge, we have shown, through a simulating model of R&D activity, the non linear dependence existing between financed R&D projects and successful technological innovations, and the existence of a critical level of R&D activity above which there are conditions of development and below stagnation and decline. Finally we have considered some implications resulting by this study and concerning promotion of technological development by public aid in a territory. It has been shown the existence of two critical moments in the development of technologies that merit attention for aid. The first one concern prefeasibility steps for R&D projects, and the second one the moment in which there is a strong increase of financial needs accompanied by a still high incertitude about project success during the development phase.

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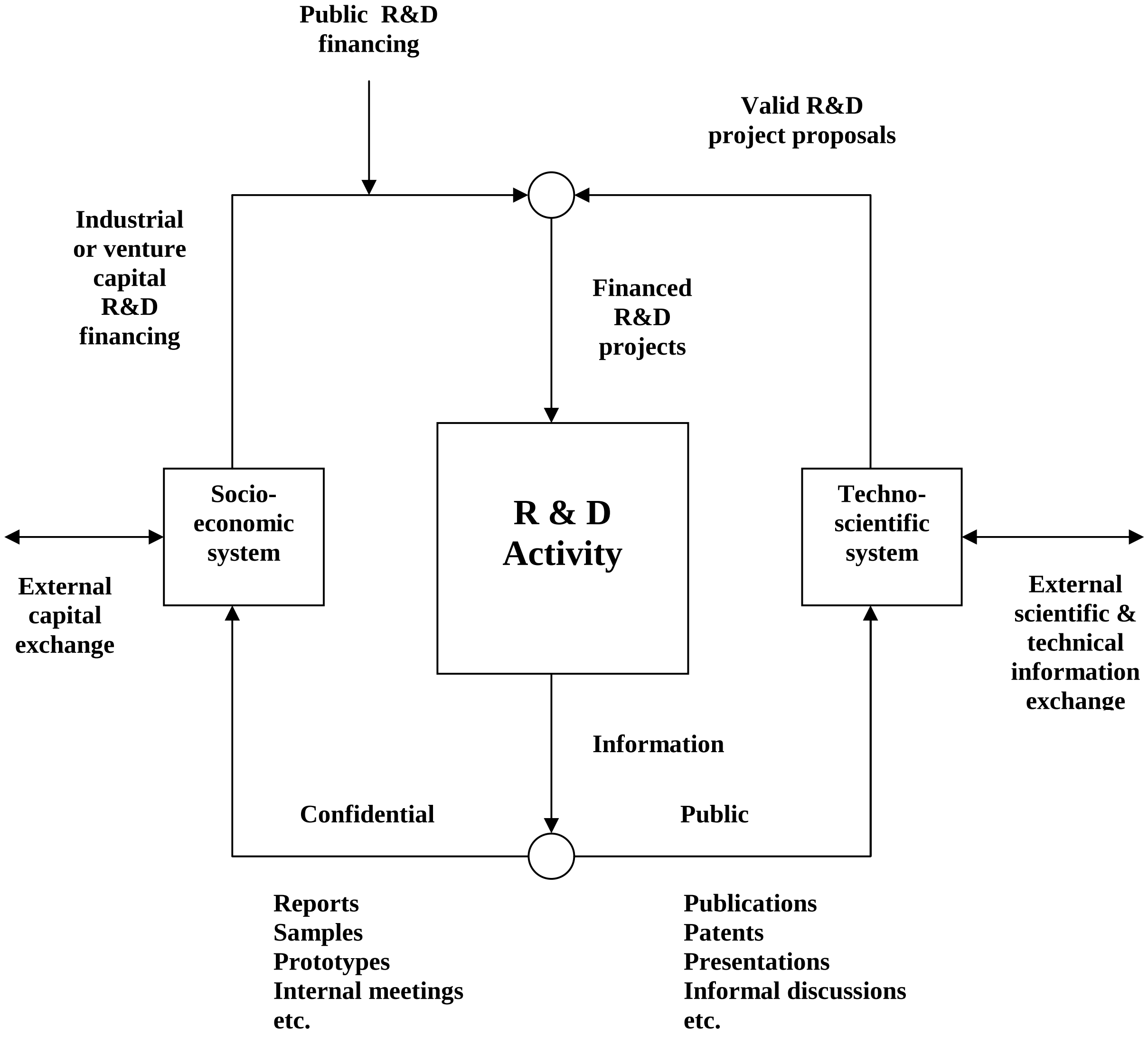

Fig. 1. Schematic view of the model of research & development activity

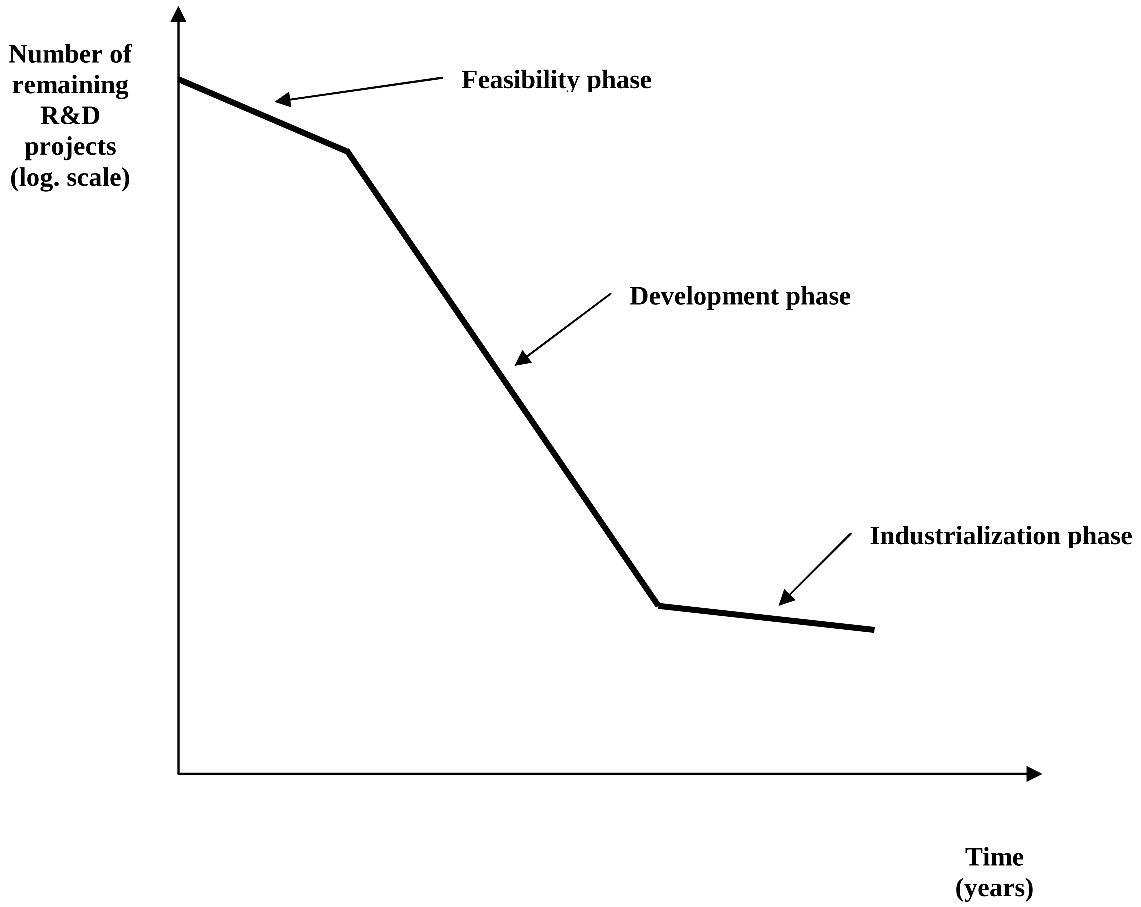

Fig. 2. Evolution of number of R&D projects as a function of time

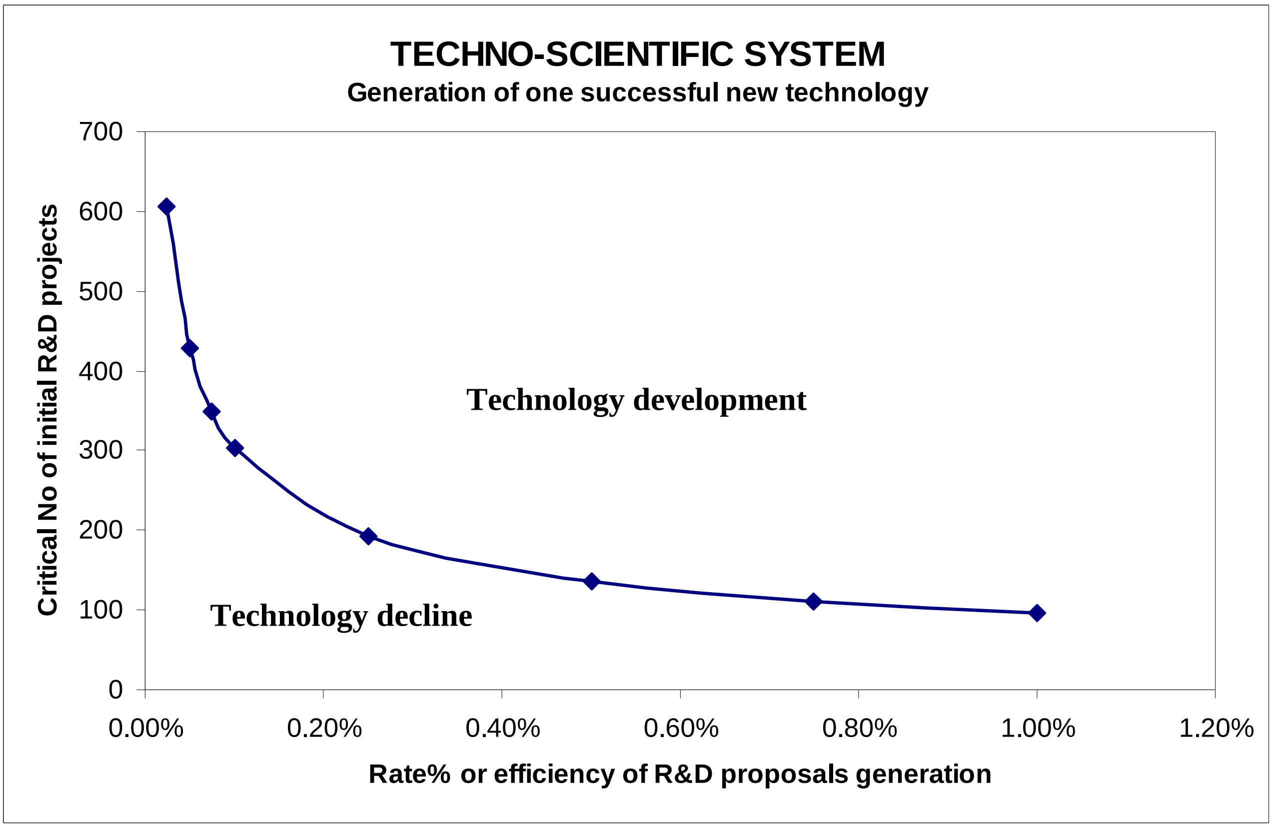

Fig.3. Critical number of initial R&D projects necessary for one successful new technology

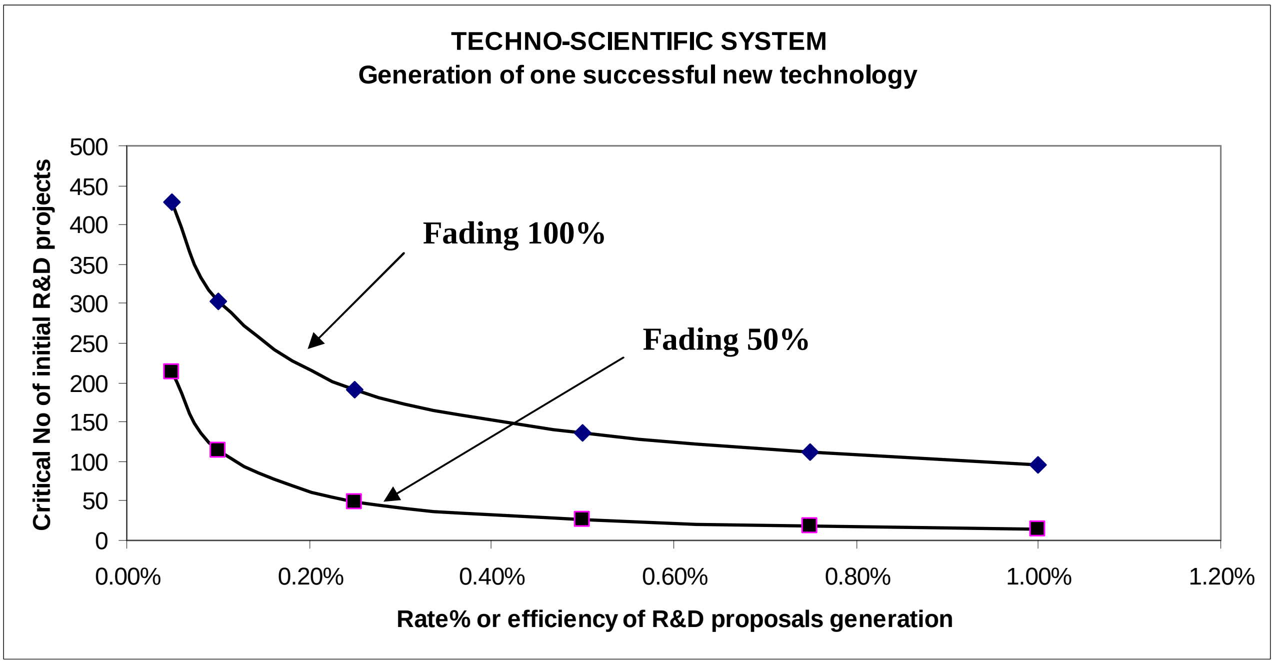

Fig.4. Influence of fading rate on critical number of initial R&D projects