Modeling Technology Innovation in Small and Medium Enterprises

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1. INTRODUCTION

It is well known that technology innovation in SMEs making conventional products is carried out mainly by learning by doing and only in minor part by R&D activities. For learning by doing in SMEs we intend not only tests carried out on industrial plants to improve technology efficiency but also changes in plant technologies to make new improved products, introduction of new equipment, and adaptation and use of technologies existing in other industrial sectors. For R&D we intend laboratory research concerning feasibility studies and development of a new technology to an industrial application stage. Prevalence of learning by doing activities in SMEs making conventional products restrains most of their technological innovations at an incremental stage excluding almost entirely radical innovations. Such fact limits the competitiveness of the firm especially in the medium and long term versus potential radical innovation of conventional products in the frame of globalization of productions. This situation is resulting by many factors that make difficult to SMEs to carry out R&D (Bonomi A. Haour G. 1993). Such factors concern: lacking of financial means, lacking of human resources and competences especially in the case of innovations requiring new knowledge for the firm. Another handicap is constituted by the fact that SMEs, rarely have suitable laboratories for R&D and, when it should be done, contract research with external laboratories is necessary. These facts raise problems about an effective exploitation of results of work of external laboratories in SMEs whose innovating experience is limited mainly to learning by doing. For these reasons when promoting technology innovation in SMEs making conventional products it would be useful to look at learning by doing and R&D activities from a common point of view overcoming the existing differences. This paper presents a model of technological innovation that integrates from the same point of view either R&D or learning by doing to favor exploitation of R&D activities and has been inspired by a previous mathematical model concerning learning by doing (Auerswald P. Kauffman S. Lobo J. Shell K. 1998**)** and extended after to R&D activities (Bonomi A. Riu A. Marchiso M. 2007). This model is the result of a long practice in helping SMEs making conventional products to develop technological innovations with some radical character by using R&D. In the second chapter we present the model in which technology is considered a structured ensemble of technological operations and dynamic changes of this structure represent technology innovation. Each technology operation may be characterized by a series of parameters, each assuming a certain number of discrete values or choicest hat may be represented in a technological space and transformed in a fitness or technological landscape by associating efficiency values. A family of different technologies with the same application purpose may be also represented in a space of technologies in which the distance between a new and an old technology represents a measure of the radicality of the innovation. In the third chapter we discuss technology innovation as an exploratory search either in the technological space or in the space of technologies. Technology is seen as an evolving process starting with prevalent R&D activities and concluding with prevalent learning by doing activities. Technology innovation is subjected to intranalities representing the effects of change of a technological operation on the efficiency of the others ones existing in a technology. A technology is influenced by many factors for example of economical or social nature that modify the technological landscape and originate the need of innovation and new technologies. Such factors constitute the externality of a technology. In the fourth chapter we present some applications of the model concerning management of technological innovations in SMEs and based on suitable structuring of technologies in term of technological operations. Applications are important especially in searching potential technological innovations and introduction of new technologies in conventional products as well as in organizing R&D cooperation in industrial districts composed by firms making the same type of products. Spaces of technologies and fitness landscapes elaborated by the model are useful in patent intelligence studies and to explain important aspects of competition among firms. In a fifth chapter we discuss promotion of technological innovations taking account of the various phases of development that characterize R&D activities dedicated to innovations with some radical character. Using a simple model of R&D activities describing technology innovation as result of a combinatory process of previous existing technologies and contributions of scientific knowledge, we show that innovation development is highly dependent on the strength of the scientific and technical system exiting in a territory and that strengthening of such system is more important than availability of funds for R&D in assuring technological development. In the sixth chapter we present the conclusions of our work and finally in the appendix we describe the mathematical aspects of the model of technology and an application to experimental planning in R&D activities.

2. MODEL OF TECHNOLOGY

The development of a model of technology innovation in fact implies the development of a model of technology as technology innovation may be seen as a dynamic process occurring in the technology. There are many possible approaches to modeling a technology depending on whether technology is considered as a process or as an artifact. Modeling technology as a process means considering a technology as a structured ensemble of technological operations in sequence with time (Auerswald P. Kauffman S. Lobo J. Shell K. 1998) and **(**Bonomi A. Riu A. Marchiso M. 2007).. For example a thermal treatment technology may include three technological operations of heating, maintaining in temperature and cooling. Modeling a technology in term of an artifact means to consider the artifact as an ensemble of structured components (Frenken K. 2001). For example a car will have as components engine, brakes, wheels, tires, etc. The choice of the approach depends on the application considered for the model. For example chemical technologies or production technologies occurring in various steps are studied better considering technology as a process, while complex mechanical products such as cars, airplanes, etc. or electronic devices may be advantageously approached in term of technological components. Finally it should be considered that in the case of artifacts there is a further possibility of modeling in terms of processes related to functioning of the artifact. In this work we have considered mainly the approach to modeling technology as a process as considered applications were better studied with this approach. In any case modeling in term of components has in fact similar definitions, concepts and mathematical description as those used for an approach in term of processes and this analogy will be briefly presented in the description of the model. Technological operations are in fact also technologies that may be further structured and choice of the necessary degree of detail of a given structure of a technology depends in fact on the type of application.

Modeling technology in term of processes means that a technology is defined by a structured ensemble of technological operations, as described previously in the example of thermal treatment. In more complex technologies it may include not only a sequence of operations but also operations in parallel. The structure obtained is similar to the elaborated tasks structure when using PERT method, well known in project management (Bonomi A. Riu A. Marchiso M. 2007). Each technological operation is characterized by a certain number of parameters. For example the operation of heating in thermal treatment is characterized by a speed of heating and a final reached temperature, maintaining operation by its duration time and cooling by speed of drop of temperature. Furthermore each parameter may be associated to an ensemble of discrete values or choices in certain established range. For example heating temperature may assume values between a maximum and a minimum with a step of one degree °C. In this way a technology may have a certain number of specific configurations or technological recipes characterized by the specific values assumed by all parameters of all operations. The number of configurations or recipes is then resulting by a combinatory calculation based on number of operations, parameters and possible assumed values for a given technology. Using the concept of Hamming distance it is possible to represent all technology recipes in a multidimensional, discrete space in which a point represents a configuration and distance among points is proportional to difference among the various recipes. Such space is called technological space. Each technological recipe may be characterized by a value of efficiency that may be of various types. For example there is an economic efficiency specific of a particular recipe related to unitary cost of production but also an energetic efficiency related to consumption or production of energy and an environmental efficiency based on degree of elimination of contaminants. Of course, as technological operations are themselves technologies, it is possible to define also an efficiency of the technological operations whose values contribute to the overall efficiency of the technology. It should be noted that efficiency is not depending on a specific technology but it is a characteristic of a specific recipe of the technology. If we associate the correspondent scalar value of efficiency to each point or configuration of the technological space we obtain a fitness landscape called technological landscape. In such landscape many recipes may have very low values or medium values of efficiency while one or more recipes may have optimal values. In practice, for reasons that may be explained mathematically (Kauffman S. Lobo J. Macready W. 1998**)**, it is uncommon that a technological landscape appears monotonous with a single optimal value of efficiency but it owns frequently a certain number of optima of different value and in many cases the landscape is rugged presenting many optima of efficiency of similar value.

In the model a technology is specifically defined by its structure of operations, however in practice we may observe the existence of a certain number of different technologies that satisfy the same human purpose (Arthur B. 2005, 2009). Such ensemble constitutes a family of technologies that in certain cases are similar with minor changes in the structure of the operations, but in other cases may have a great number of changes that concern nearly all or all the operations. Also for a family of technologies, using the concept of Hamming distance, it is possible to represent all these technologies with the various structures in a space called space of technologies in which each point represents a specific technology with its structure of operations (Bonomi A. Riu A. Marchiso M. 2007). The distance among technologies is then proportional to their respective difference in the structure of operations, and the distance existing between an old technology and a new competitive technology may be considered a measure of the degree of radicality of the new technology corresponding to what is considered a discontinuity in technological innovation (Nelson R.R., Winter S.G. 1977, Dosi G. 1982**)**. However, it is not possible to define a fitness landscape related to the space of technologies as efficiency of a technology, as told before, depends on the chosen recipe and not by technology itself. Of course it would be possible to associate a technology to an optimum value of efficiency of its technological landscape, and build up a fitness landscape of the space of technology. However, it should be considered, that rarely a technology has a single optimum in its landscape and it would be difficult to define a standard choice of optimal values of efficiency. Finally we can make some considerations on the modeling approach of technologies as artifacts composed by various components. It can be noted that it is possible to have in this case a similar model in which components are equivalent to technological operations and characteristics equivalent to parameters that may assume also various discrete values or choices in a determined range. In this way it is possible to define also a technological space for an artifact and a technological landscape defining the efficiency for all existing configurations. In a similar way it is possible to consider an ensemble of various artifacts satisfying a similar purpose and define a space of technologies referred to these artifacts. The distance in this space between an existing artifact and a new competitive artifact may be considered a measure of the degree of radicality of the new artifact.

3. TECHNOLOGY INNOVATION

A new technology may be considered, in the simplest case, the result of changes in the technological landscape of an existing technology, but normally it involves also modifications in the space of technologies in which minor changes corresponds to incremental innovations and large changes to radical ones. Considering for example a technology of thermal treatment a simple change, such as variation of maintaining time in temperature may be an improving innovation although it cannot be really considered a change in technology as its structure remains the same. Introduction of an intermediate cooling operation and a second maintaining period at lower temperature before final cooling may be instead considered a new technology of incremental nature as there are some changes in the structure of operations. The technology taken as example is perhaps too simple to have radical innovations but if we consider a technology of production of a material with a certain composition followed by a thermal treatment, now considered not as a technology but as a technological operation, modification of material composition that make useless a thermal treatment may constitute a radical new technology of production of the material. Following our model a technology innovation may be considered the result of an activity of exploration in the space of technologies and in the technological landscape of specific technologies searching better conditions satisfying a human purpose. Such activity is considered by the model of two types: research & development or learning by doing. It should be noted that search in space of technologies cannot be dissociated by search in the corresponding technological landscapes because it is in these landscapes that it is possible to assess the efficiency of a new technology. In fact in R&D prevail activities of search in the space of technologies while in learning by doing prevail activities of search in the technological landscape. Such view proposed by the model may be considered a possible alternative to the common view of R&D activity as composed by three steps concerning applied research, development and industrialization (Freeman C. 1974). From the point of view of the model a technology, in term of a family of incremental technologies satisfying the same human purpose, may evolve similarly to a living organism in which gestation corresponds to the R&D activity necessary to bring a new technology toward an industrial use, followed by prevalent activities of learning by doing and incremental innovations to bring up efficiency of the technology until it becomes obsolete and it is substituted by radical innovations or abandoned because useless for human purposes.

Intranality effects in technology innovation

When we introduce a change in parameters values of a certain operation to increase its efficiency, we may have effects on efficiency of other operations affecting in this way the overall efficiency of the technology. Such effect represents the intranality of the technology and exists for most of the technologies (Auerswald P. Kauffman S. Lobo J. Shell K. 1998**)** . A rare case of inexistence of intranality effects in a technology means that the technology landscape of this technology is monotonous with one single peak of efficiency. In most cases the intranality effects bring to the existence of various peaks of efficiency in the landscape and extended intranality effects result in a very rugged landscape with a high number of peaks with similar values of efficiency. Such facts can be demonstrated mathematically by the model (Kauffman S. Lobo J. Macready W. 1998**)**. An extension of intranality effect may exist also when we modify the structure of a technology for incremental innovations affecting the efficiency of other still existing operations. Such situation is important in the case of introduction of innovations in a production technology in which various operations are carried out by independent firms, as in the case of industrial districts making similar products, and may be an obstacle to adopting a new technology. When technological operations are controlled by more than one parameter or instruction, intranality effects may not necessarily concern all parameters of an operation. That means intranalities shall be studied as dependent on instructions instead of operations and relations of intranality may exist or not among the whole ensemble of instructions and operations of a technology. Finally we may note that, as consequence of intranality effects, the search of optimal conditions of efficiency may require a tuning work on parameters values of other operations to obtain a real improvement of the technology.

Externality effects and technology ecosystem

The efficiency of a technology may be influenced by a great number of factors of various types for example of economic, social, politic, and environmental nature and even by dynamic of other technologies. Such influence on efficiency of a technology is called the externality and has the consequence to modify the aspect of its technological landscape making reduction or disappearance of peaks of efficiency and raising of peaks in other regions of the landscape. As it is possible to define various types of efficiency of a technology the effects of externalities are a function of the chosen type of efficiency. As consequence of externalities a technology landscape is in this way continually changed and learning by doing and R&D activities are continuously necessary to conserve efficiency through modifications of technological recipes or even adopting new incremental technologies and, in rarer cases, by introduction of new radical technologies. From the point of view of the model it is possible to study the externalities effects of a certain number of chosen factors. Each factor may be characterized by external parameters assuming a certain number of values or choices. In this way externality may be described by a certain number of configurations resulting by a combinatory calculation similarly to what is done for technology recipes. The number of calculated configurations corresponds in this case to the number of technology landscapes configurations generated by externalities on a specific technology. Considering now the various factors of externality, such as for example increasing of costs of energy or raw materials and their availability, social and politic factors modifying the acceptance of the technology or even environmental factors that modify norms establishing acceptable levels of contaminants, there are specific externalities that concern the relation of a technology with other existing technologies. The fact is that technologies operate in an ecosystem similar to biologic ecosystem in which they appear, compete and disappear by effect of complex relations existing among technologies of the entire ecosystem (Arthur B. Kauffman S. in Waldrop M. 1992**)**. A typical dynamic in such ecosystem is represented for example by emergence of automobiles in the human transport in alternative to the use of horse powered carriages. The disappearance of horse powered transport had the consequence of disappearance of other technologies for example in the construction of carriages, fabrication of horseshoes and existence of coaching houses. On the other side the development of automobiles has been accompanied for example by development of technologies of production of engines, gasoline and tires and diffusion of service stations. In the technological ecosystem are all more or less correlated. For example it may be even found a relation between technology of construction of cars and that of electronic devices such as computers or photovoltaic cells. In fact all these technologies make use of silicon that is an important alloying element for certain parts of car engines and an essential material for electronic components and solar cells. In fact the amount of silicon used for electronic and solar application is only a very minor quantity in respect to the amount of metallurgical silicon used in engines. That has as the consequence that production technology of electronic and solar silicon is advantageously produced starting with metallurgical silicon instead of use of specific technologies from silica containing raw materials. On the other side at the beginning of development of use of solar silicon, downgraded electronic silicon was available for such purpose reducing the interest in specific technologies for the production of such material. If by hypothesis in future in the human transport internal combustion engines will be substituted by electric motors, the demand of metallurgical silicon will probably disappear and alternative technologies of production of electronic and solar silicon will be of interest starting for example by high purity sands instead of the present use of silica containing stones for production of metallurgical silicon. This example may give a good idea of how apparently far technologies are in reality related and how externalities effects among technologies may affect the dynamic of evolution of technologies.

The analogies existing between descriptions of a technology in term of components instead of processes, as briefly presented in the previous chapters, may be easily extended to dynamic of learning by doing and R&D activity concerning the innovation of an artifact. In the same way it is possible to define intranality effects among components efficiency of an artifact and externality effects on technology landscapes referred to its components structure.

4. APPLICATIONS OF THE MODEL

The starting point of any applications of the model is the structuring of technology in term of technological operations. As such operations are themselves technologies, the structuring of a technology should be done to a suitable level of detail necessary for the considered application. Technological operations have an important role in describing technology innovations, R&D and learning by doing activities made by SMEs. In Figs. 1 and 2 we have reported two examples of simple structuring of two typical technologies concerning respectively production of taps & valves and metallic households used in various studies. Before entering in description of applications, it is useful to recall how the model sees learning by doing and R&D activities and which are the differences between entrepreneurs and managers of SMEs in respect to researchers in R&D laboratories in the approach to such activities.

Learning by doing activities

Learning by doing is the more common way to make technological innovations in SMEs. It includes not only testing improvements of the various technology operations but also introduction of new equipments and adaptation of available new technologies often already used in other industrial sectors. From the point of view of the model such activity may be described in the simplest case by a change of parameters values or choices in technological operations looking for better efficiency by searching an optimum position in the technological landscape. The other types of learning by doing activities correspond essentially to elimination, substitution or addition of one or more operations in the technology structure, searching optimal conditions either exploring the technology landscapes and space of technologies. Generally such changes are limited in number generating only incremental innovations. The use of scientific knowledge in learning by doing is limited and concerns essentially the suggestion of regions of the technology landscape in which it is more probable to find an optimum of efficiency.

Research & development activities

Research & development is a common way to make technology innovations. It includes feasibility studies, typically in research laboratories, and technological developments through pilot plants experience or building prototypes in order to assure to the new technology sufficient performance, suitable costs and market acceptance of products. From the point of view of the model such activity may be described as an exploration of both space of technologies and technology landscape of specific technologies of the space. Scientific knowledge plays a role in orienting exploration in regions of the space of technologies and technology landscapes in which it is more probable to find conditions of feasibility and optimal parameters values for a new technology. In certain cases it may be useful to carry out also typical scientific research to find new data and knowledge relating to the R&D activity in what is generally called oriented research. Finally it should be noted the important role played by introduction of new phenomena discovered by science and never exploited before, in the elaboration of new technologies especially with a high radical character. R&D activity may

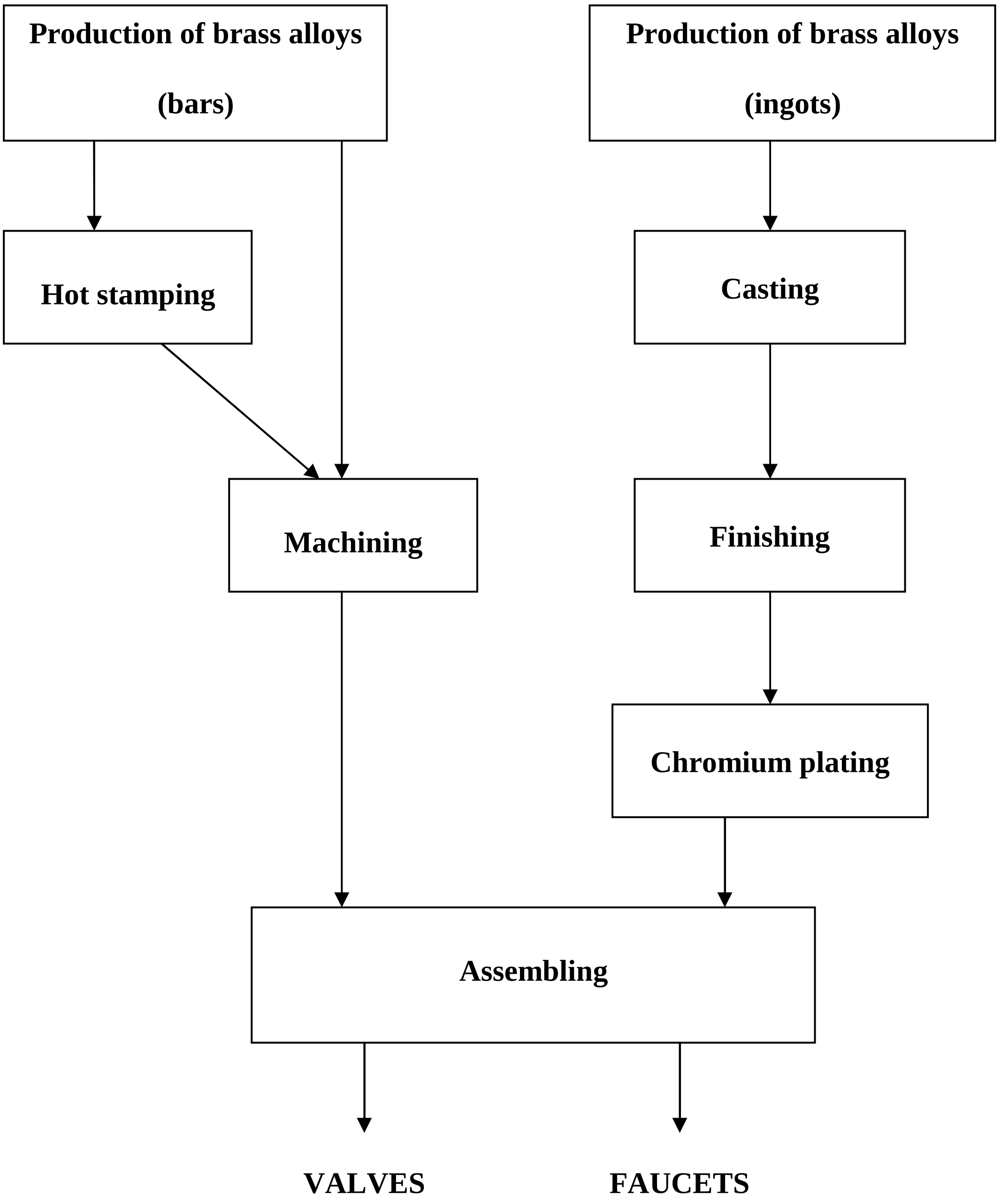

Fig.1. Technological structure of operations in production of taps & valves

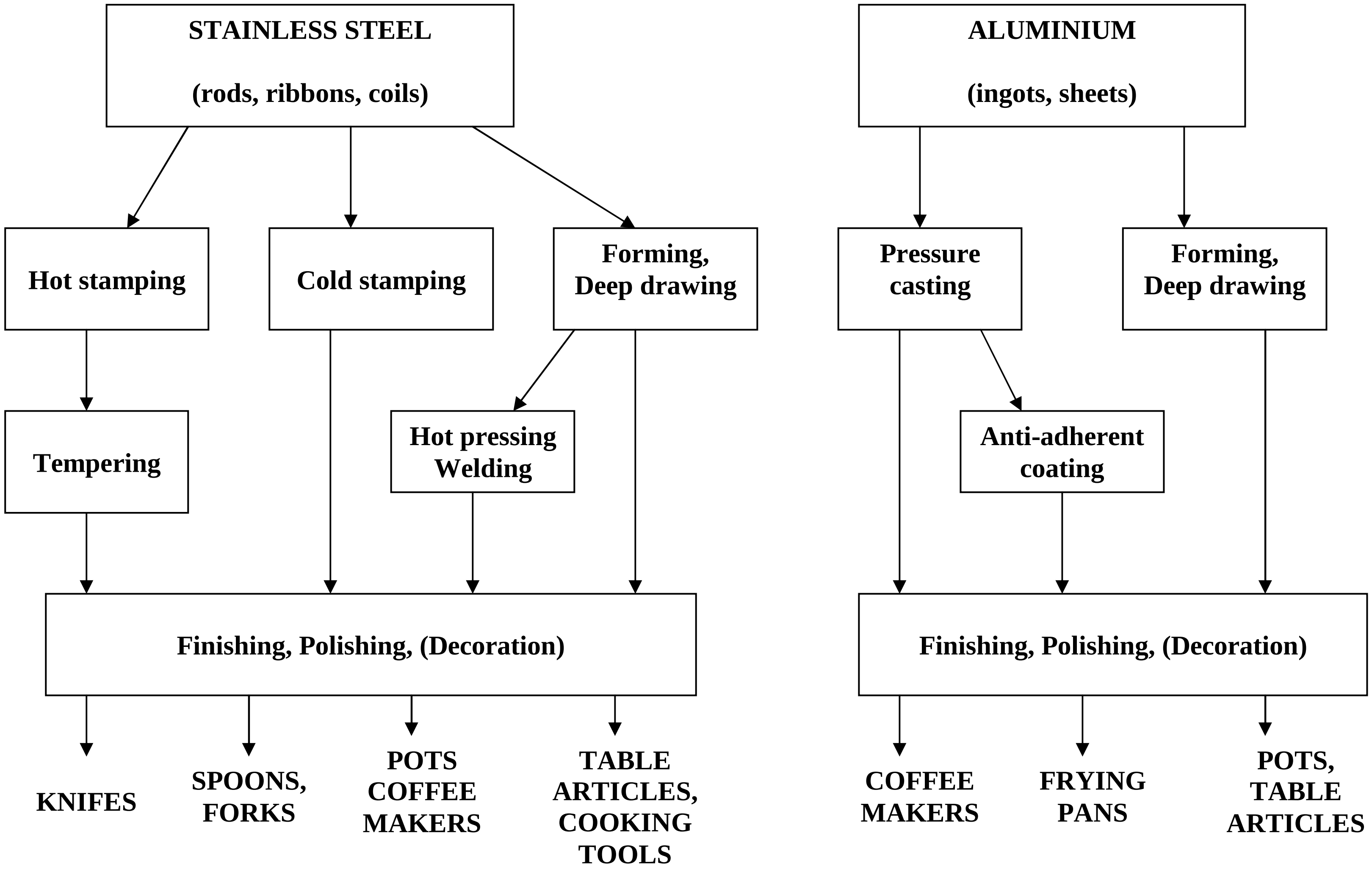

Fig.2. Technological structure of operations in production of metallic household

concern a large number of changes in technological operations and it is practically now necessary to develop radical innovations.

When considering exploitation of R&D results coming from external research laboratories by SMEs, it should be noted the different points of view existing between entrepreneurs or managers of SMEs and external researchers about the work done and obtained results. Managers of SMEs will essentially consider results and possible technology innovation in term of changes in their technology operations and consequent effects on the production activity and economic impact, researchers will see results in term of technological feasibility and corresponding scientific or technological aspects. Such different points of view may generate possible conflicts about exploitation of results. Such conflicts exist also in large companies between people of internal R&D laboratories and production managers but it could be normally settled by top management decisions. This is not the case of SMEs in which generation of results and their exploitation are done by two independent bodies and it is often followed by interruption of financing and end of project by SME. This conflict is particularly sharpened when R&D is carried out in universities in which researchers may have a good scientific and technical knowledge but are not prepared to consider the other aspects of an innovation. Such situation may be worsened by low experience in management of R&D results by SMEs accustomed to make innovations only by learning by doing. This is not generally the case of large industries collaborating with universities whose managers have generally a good experience in R&D and technology management, The use of the model in explaining the results in term of nature of technology and technology innovation should help to solve such problems between laboratories and SMEs by converging the different points of view on a common assessment and possible exploitation of R&D results. This could be done by concentrating efforts on both technical and scientific aspects as well as on economic and production impacts. Intranalities existing in studied technological operation changes may be an useful common base of discussion between contract research laboratories and SMEs. However the lack of experience in technology management and especially in the strategic use of technological innovations for competitive purposes existing in SMEs making conventional products remains a major obstacle to development of innovations in such type of firms.

An important application the model concerns the identification of the more interesting technological innovations that may lead to introduction of new technologies in conventional productions. Another application concerns efficient organization of cooperation projects for technological innovations. The model may also be useful in patent intelligence studies and explanation of the existing competition processes among firms and few other possible applications not already tested in practice. Such types of applications are detailed as follows.

Identification of technological innovations and introduction of new technologies

Generally identification or introduction of technological innovations in conventional production is originated by working experiences, technical information and scientific knowledge concerning specific technological operations carried out. The model offers a rational and systematic approach to such work considering the entire structure of a technology and intranalities and externalities influencing the prospected changes in the technology. Two studies of this type have been carried out for example in the frame of a cooperation of SMEs in the sector of taps & valves production and one in the sector of metallic household production (Bonomi A. Castellero A. Ricchiardi G. 2008). The basic work concerns an elaboration of the operational structure of the technology to be innovated with a suitable detail confronted with changes suggested by information coming from internal or external experience, technical and scientific literature, normally done through data bank interrogations and discussion with experts involved in such innovation. Patent intelligence studies are also useful to identify already patented innovations giving useful suggestions for the innovation process. Such type of preliminary study is rarely done by SMEs that are accustomed to do learning by doing innovation by a direct experimentation of the innovative ideas in the frame of the current state of the art of their technology. However, such approach is not efficient in the case of development of new radical technologies. Such systematic approach by using the model has been shown useful when establishing R&D projects in starting cooperative research activities among firms with similar technological problems. Another possible use of the model concerns the introduction of new technologies, actually new technological operations, in conventional productions. That is done confronting both new and conventional technology operations in order to identify potential innovating changes. An example of such study has been made considering introduction of nanotechnologies in conventional production of tap & valves and in metallic households and that has resulted in finding four potential innovating fields in both conventional technologies (Bonomi A. 2011b).

Organizing of cooperative studies and R&D projects

Cooperation among SMEs is an important factor in technological innovation in such type of firms as it is a valid approach to solve many difficulties that SMEs have in doing R&D projects such as financial or human resources and competences availability (Bonomi A. Marenco P. 2006, Bonomi A. Rolfo S. 2012**)**. Such cooperation is particularly effective when SMEs belong to the same sector of production as in the case of industrial districts. The generation of efficient and continuous cooperation among SMEs in the field of technological innovation is a tricky operation requiring specific figures able to catalyze, organize and maintain cooperation as well as an effective generative relationship for the emersion of valid cooperative studies, projects and structures (Bonomi A. 2011a). Such generative relations are also important when carrying out identification and introduction of new technologies as discussed previously. Technology innovation requires various competences not necessarily present in a single SME but often distributed among various independent firms and laboratories. This fact makes necessary the search of partners that cover all the necessary competences for a project as resulting by an analysis of the technological operations structure and its changes. This is also valid for radical innovations in which innovative results of new competences should be confronted to conventional knowledge in order to have a good assessment of validity of new ideas substituting conventional ones.

Patent intelligence and competitiveness of SMEs

A patent is a legal document containing a technical description protecting an invention and it is basically written following rules that are quite different from those used for technical and scientific documents. For these reasons study of patents requires a specific approach. From the point of view of the model patent claims and examples delimitate a region of the technological space and landscape in which the patent protects the invention. Generally values and choices given are indicated with a large range avoiding the disclosure of optimal conditions used to operate the invention, but also to cover other possible optimal conditions that might exist in the technological landscape of the invention or in landscapes of similar technologies. Certain patents cover invention of artifacts that may be better described by the model in term of components than in term of technological operations. Beside the normal search to verify patentability of an invention, there are also useful studies, called patent intelligence, supplying interesting information for the development of a technology innovation. Such studies may define the historical development of a technology and its geographical distribution, and delimitate regions of the landscape that are protected but also others that are free and generating useful ideas for new inventions and suggestions about R&D working programs. Generally SMEs do not carry out patent intelligence study but only verifications for patentability of an invention. In many case SMEs do not even patent potential inventions protecting simply by secrecy their equipments and know how. Cost of patents delivery and protection may be too expensive for a SME considering the limited potential use of the possible patent. Further, effects of intranalities may be also an obstacle to use an invention. This is a typical case observed in industrial districts where production operations are distributed among various independent firms. Some times an innovation considered by a firm requires for its use changes or new investments in other operations that in fact are carried out by independent suppliers that for various reasons may be not interested to do. The consequence is a loss of interest to develop and patent such innovation. The description of patents in term of protected regions of technological landscapes arises some interesting implications concerning competitiveness of firms. Generally a patent includes examples and claims concerning not just a single technology with a specific structure of operations but an ensemble of similar technologies with the same application purposes. When new technologies of such group are, as frequently happens in the case of SMEs, only incremental, the patent covers limited regions of the space of technologies. Other regions are held by patents of current technologies and other ones may be open to new patentable technologies. Similar technologies with only few differences in the operation structures have probably similar landscapes that are normally characterized by rugged structures containing many peaks of efficiency of similar value. That means that when a firm owns a patent covering an incremental innovation, not necessarily the protected region includes all possible technologies potentially competitive. By consequence a competitor with similar competences may find relatively easily other optimal positions in the landscapes not protected by the original patent eliminating the temporary gap of competitiveness generated by the previous patent. This type of compensation of competitiveness may occur repeatedly entering in what it is called a red queen regime, term used for similar situations existing for competition in biological ecosystems. Such regime is characterized by a continuous evolution of technology but little changes in firm competitiveness as it is observed frequently in industrial districts. An effective increasing of competition in such regime is possible only by reaching higher speed of innovation to assure a continuous higher level of competitiveness in respect to firms with lower innovation speeds, or even by introduction of radical innovations requiring new competences not easily available leading to exclusion of other firms from the new obtained markets. On the other side firms that do not make innovations or make it at a too low speed are fatally destined in a red queen regime to decline and extinction.

Other applications of the model

There are other possible applications of the model that in fact had been never tested but that are enough interesting to be cited. The first one concerns the problem of closure of a large industry in a territory with consequent generated unemployment and other unfavorable economic consequences. Such situation is frequently observed especially in territories with an old industrial history (Garnier J. 2008). Sometime spontaneously unemployment generates a certain number of SMEs that use competences existing in the disappearing industries by developing a suitable diversification of activities, but in other cases unemployment remains and competences inherited by disappearing industries are lost. It would be interesting in this case to study the problem in term of competences associated with technology operations existing in the disappearing industry in order to identify potential activities for generation of SMEs associated to a suitable diversification. Another case concerns large industry existing in a territory that subcontract work often far outside this territory. It would be of interest for the territory to find activities that could be advantageously subcontracted by SMEs existing or being generated nearby such industry with even a possible increase of the subcontracting activity. Also such study may be based on an analysis of the technological operations made by the large industry.

5. PROMOTION OF TECHNOLOGY INNOVATION IN SMEs

Promotion of technology innovation in SMEs is an important cause of concern and it is carried out mainly by public aid to innovative projects, also favoring cooperation among SMEs, universities and research laboratories. However observing actual results of such aids it might be raised some doubts about their efficiency about the way they are generally supplied. The first critic concerns the suitability of aids in relation with the various phases composing the technology innovation process. The second one concerns the efficiency of public financing and the diffused credence that results are in a certain way proportional to the available financial supports.

In order to discuss the optimal phase of technology innovation development in which the aids may be more effective it is necessary to give a description of such phases as normally are observed in technology development, especially in the case of innovations having a certain radical character and good competitiveness. We can consider for such developments the existence of three major phases. The first one concerns feasibility studies in which continuation of projects is essentially depending on technical and scientific factors, followed by a second phase of development in which continuation of projects is mainly controlled by socio-economic factors linked to production costs, performances and market acceptance, and finally an industrialization phase in which success of a new technology depend on industrial and market factors. Generally thousands of starting feasibility projects are necessary to obtain, after the various phases of selections, a few number of successful new technologies. Of course it is not possible to make statistical studies that are able to follow a very high number of initial projects for a certain number of years until their industrialization. However practical experience and indirect indications from certain studies support the existence of a strong selection in R&D project developments. A study (Scherer F.M., D. Haroff, 2000**)** concerning 1000 German patents conserved valid for at least 10 years has shown that only about 5 percent have been a great success and only about 20 percent can be considered economically profitable. Now such ensemble of patents may be considered associated to a high number of abandoned patents for lacking of interest or by effect of litigations as well as a high number of R&D projects abandoned without making patent applications. It is evident that all these considerations are a strong support of the existence of a very high degree of selection. The situation may be represented indicatively on Fig. 3 where the logarithmic number of remaining projects, after an initial high number starting ones, is given as a function of time (years) for the mentioned three phases of development. It may be noted that the major loss of projects is not in feasibility or industrializing phases but in the intermediate phase of development controlled by socio-economic factors. From the economic point of view a project in this phase is faced to a great increase of costs and limited reduction of uncertainty about its success and such phase has been called the Death Valley of R&D projects (Branscomb L. Morse K. Roberts M. Boville D. 2000). On the other side there are often available public aids for the industrialization phase with doubtful results although it is well recognized that this phase should be effectively supported by industrial and financial capital. Typical public aids to R&D are mostly concentrated on final feasibility phase and beginning of development phase (precompetitive projects) and such fact is questionable in term of efficiency. On the other side cost of feasibility phase projects is low and for such phase there are no reasons to be easily financed by industry and even by SMEs despite the high uncertainty existing for projects in this phase. The real need of public aid, especially in the case of SMEs, is actually in the development phase where high uncertainty is accompanied by relatively high financial needs. About the feasibility phase it might be considered another type of aid particularly interesting in the case of SMEs carrying out R&D essentially by contract research. Presently public aid is often offered only in the case of existence of an agreement between SMEs and a research laboratories to carry out a project. In fact it would be more effective if aids would be available directly to research laboratories dedicated to industrial innovations and in measure to make prefeasibility studies that may raise a real interest in SMEs promoting also possible cooperation among SMEs about the project. Such laboratories may be made available also by encouragement of spin off from universities for such purpose.

Concerning another limiting aspect of efficiency for public financial support to R&D that will be better understood using a simple model simulating the R&D activities in a territory based on the combinatory nature of technologies and scientific knowledge available (Bonomi A. 2010). Such

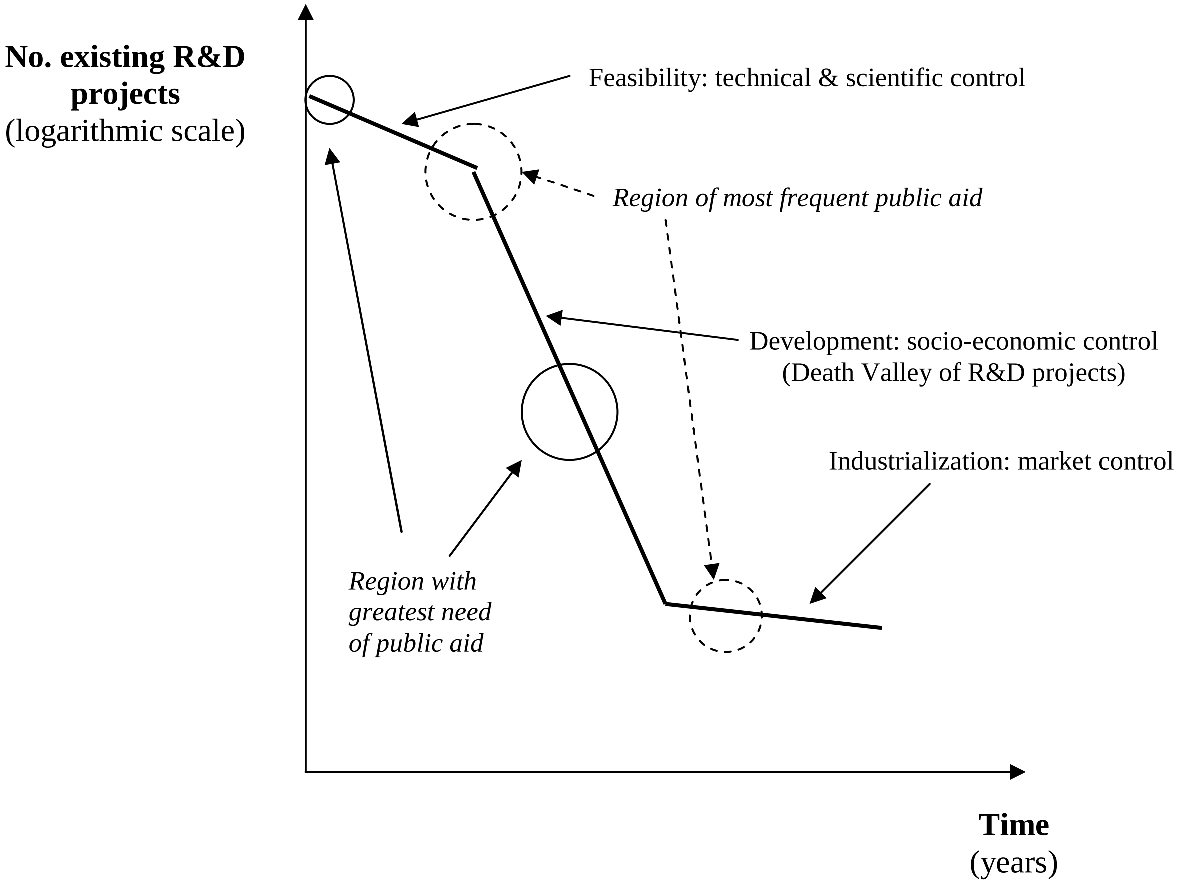

Fig.3. Dynamic of selection of R&D projects

model has been inspired by previous schematic representations of the R&D activity (Dumbleton J.H. 1986). A schematic view of the model is represented in Fig. 4. The R&D activity is the result of R&D projects proposals that meet adequate financing by industry and public aid. The R&D activity generates essentially information on studied operations for new technologies. Such information is of two types. The first one is confidential and includes reports, samples, prototypes, etc. that are used by the industrial and financial system to eventually industrialize the new technology and generate margins that may be partly used to finance further R&D activity possibly integrated by public aids. The second one is public and concerns publications, patents, presentations, etc. that may be used to generate new R&D project proposals in the territory. New projects proposals are the results of a combinatory process of information generated by past R&D projects with added scientific and external technical information (Arthur B. 2009, Fleming L. Sorensen O. 2004). For calculations each R&D project has been considered a source of a certain number of packages of information available for combinatory purposes independently of the fact that such packages are resulting from successful projects or not. The calculated number of combinations is increased of a certain percentage to take account of intake of scientific and external technical information. Each combination is a potential proposal for a new R&D project and the percentage of combinations that become finally financed R&D projects is considered a measure of the efficiency of the techno-scientific system of the territory. The R&D activity of the model proceeds by periodic cycles of execution of R&D projects, generation of packages of information and selection of financeable new projects. A fading effect of packages originated in past cycles is considered in calculation of available combinations for R&D project proposals. Starting with an initial number of R&D projects possibly financed by a public aid in a territory, the availability of further valid financeable R&D projects in a second cycle is resulting from the number of generated packages of information and by efficiency of the techno-scientific system of the territory. Depending on such efficiency, it is possible that the number of generated valid projects for a second cycle would be inferior to the initial number of financed projects and the system will reduce to near zero future available projects after a certain number of cycles. In fact it is important that the system will be able to generate a higher number of R&D projects than the initial one in order to be in measure to generate, at least after a certain number of cycles, some successful new technologies for the territory, otherwise the system is condemned to a technological decline with its consequences. Only when the number of initial projects and techno-scientific efficiency are above certain critical values there are conditions of technological development. This situation is represented in Fig. 5 in which the curve indicates the critical number of initial R&D projects able to generate at least one successful industrial application as a function of the efficiency of the techno-scientific system of the territory. For the calculation of such curve it has been assumed in this case that every project generates an average of three information packages and the number of calculated combinations is increased of ten percent to take account of support of scientific and external technical information. The fading effect on packages of past cycles has been considered 50 percent. The area below that curve indicates couples of values of number of projects and efficiency unable to generate technological development and area above such curve couples of values able to generate such development. In order to make calculation for the curve it is necessary to know statistical data indicating the rate of success of R&D projects for industrialization and the rate of success of industrialized projects in term of profitable return of investments. In fact such type of statistical data are not available, however study on profitability of patents and practical experience may give an order of magnitude of such parameters. In the presented case of Fig. 5 it has been considered a rate of success of one percent for industrialization of R&D projects and a rate of 20 percent for profitable success of industrialized new technologies. Concluding the model shows that simple financing of R&D projects in a territory could be highly ineffective if there is a weak techno-scientific system, and financing should be more effective if it is used to strengthen this system before supporting R&D projects.

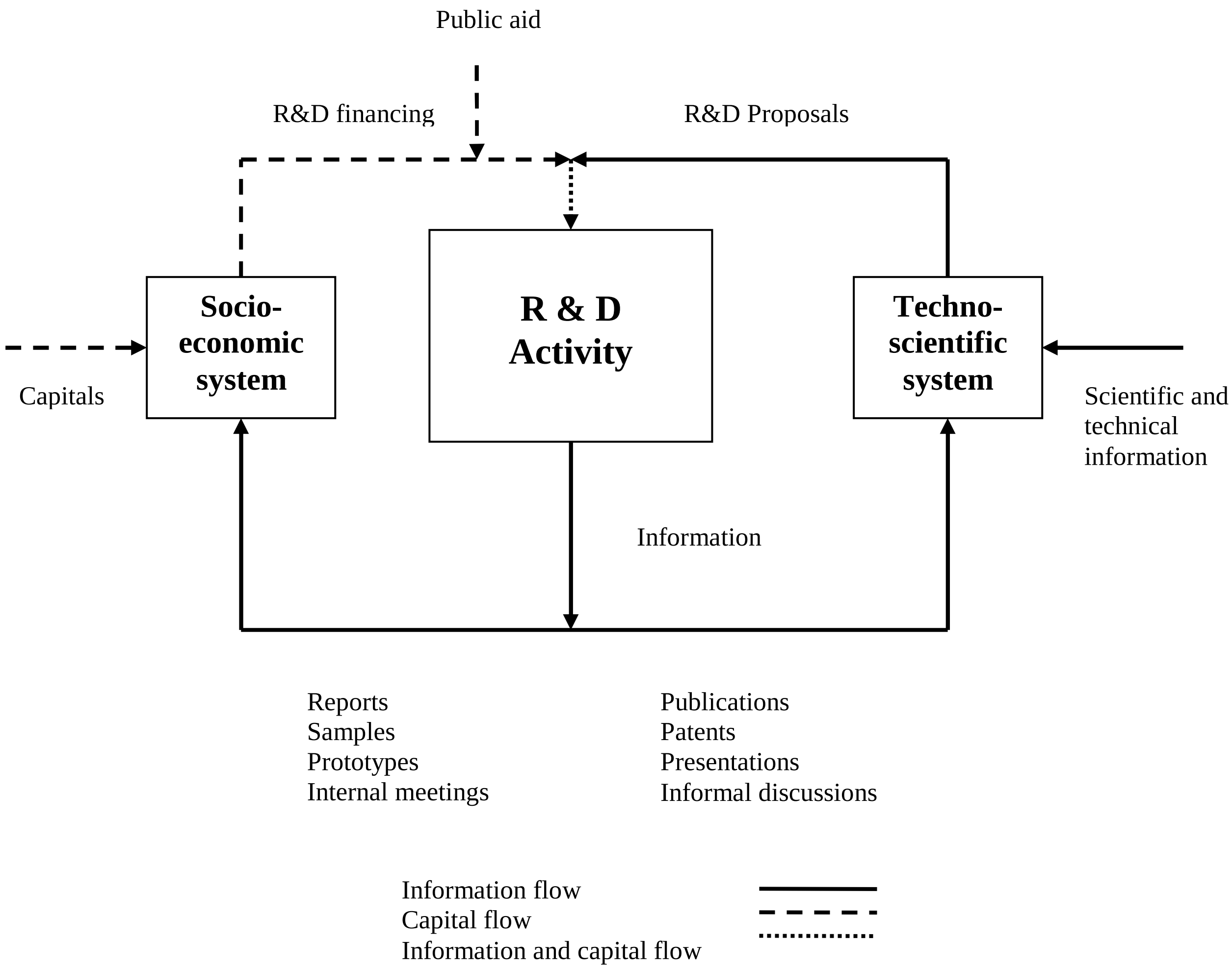

Fig. 4. Model of R&D activity

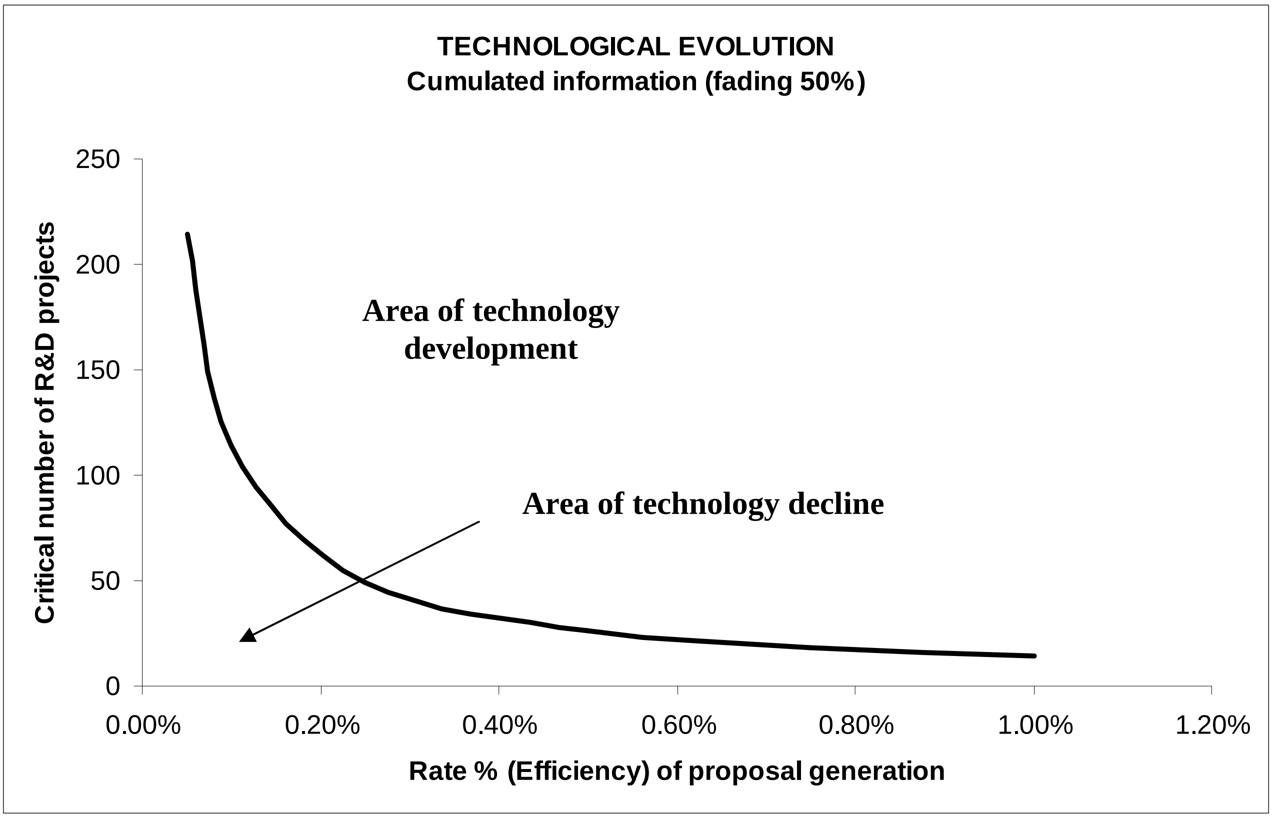

Fig. 5. Evolution of critical number of R&D projects giving in average at least one successful innovation as a function of the efficiency of the techno-scientific system in a territory.

6. CONCLUSION

Concluding the model of technology innovation discussed in this paper has the advantage to present R&D and learning by doing as part of a same type of process of change of technology in the development of innovations. Such view is of great interest considering that technology innovation in SMEs making conventional products is generally done by learning by doing without real important experience in R&D despite of interest to turn to this activity to generate more radical and competitive innovations. In SMEs the R&D is commonly carried out by contract research with external laboratories and for an effective exploitation of results it is necessary to obtain a convergence between views and experiences of SMEs and these of external laboratories carrying out the research. Such convergence may be helped by using various aspects of the model that integrate from the same point of view R&D and learning by doing. Essentially the use of the model is based on structuring a technology in term of technological operations or components of an artifact. Such mode of approach to technology in terms of operations is not new and it is currently used, however the model offers a systematic and rational method for such work supplying definitions and concepts that may be useful for a general view of the innovation process. Technology innovation is seen as a change in this structure and parameter values used for operations taking account of intranality effects resulting by proposed modification of technology. Furthermore the model indicates the numerous factors influencing the efficiency of a technology and constituting its externality.

Applications concern identification of the most interesting R&D projects and introduction of new technologies in SMEs products and productions as well as organization of effective cooperation and patent intelligence studies. About promotion of technological innovation in SMEs it is stressed the existence for R&D of three phases in its development in which various factors control the selection of the various projects. A simple model of R&D activity based on combinatory nature of technological innovation shows that technological development of SMEs in a territory depends more on the presence of an efficient technical and scientific system than in the availability of financing and public aids to R&D. The promotion of technological innovation in SMEs would be more effective in helping private laboratories or spin off from universities dedicated to R&D for industry to make prefeasibility studies on new technologies, promoting cooperation and searching interested firms for such developments, instead of financing directly predefined projects by single SMEs and research laboratories. On the other side financial help to SMEs is specially needed in the intermediate phases of development of an innovation, the “death valley” of R&D projects, more than in the case of feasibility studies.

APPENDIX

MATHEMATICAL ASPECTS OF THE MODEL

1. MODEL OF TECHNOLOGY

A technology may be considered a structured ensemble of technological operations. For example, a technology such as heat treatment may consists simply in three technological operations of heating, maintaining in temperature and cooling in sequence with time. More complex technologies may not simply consist in a sequence of operations but they may have also operations in parallel. Each operation may be characterized by a certain number of instructions or parameters assuming a certain number of values or choices in a certain range. In Table 1 there are reported some examples of operations and corresponding instructions.

Table 1. Examples of technological operations and instructions

OPERATIONS	INSTRUCTIONS
Heating	Reaching emperature
Maintaining at a certain temperature	Time
Cooling	Velocity of cooling
Transportation	Speed
Moving	Distance of displacement
Drilling	Depth of penetration
Charge an electrical capacitor	Values of electrical capacity
Use an electrical resistance	Values of electrical resistance
Compression	Pressure
Mixing	Chemical composition
Dissolution	Concentration

Considering now a technology characterized by a set O composed by N operations o_i we have:

$$O = \{o_i, i = 1, ..., N\} \quad (1)$$

Each operation o_i is characterised by a set M_i of M_i specific instructions p_{ij}:

$$M_i = \{p_{ij}, i = 1, .., N ; j = 1, \dots, M_i\} \quad (2)$$

In which p_{ij} represents the jth instruction associated with the ith operation o_i. The total number P of instructions characterising a technology is given by:

$$P = \sum_{i=1}^{N} M_i \quad (3)$$

The instruction p_{ij} may assume a set S_{ij} of different values or choices s_{ijk} :

$$S_{ij} = \{s_{ijk}, i = 1, ..., N ; j = 1, \dots, M_i ; k = 1, \dots, S_{ij}\} \quad (4)$$

In which S_{ij} indicates the cardinality of the set S_{ij}.

The N operations cannot be considered simply a set as in fact they have normally a specific time sequence. Operations can be represented by a graph constituted by nodes, corresponding to the events of starting and/or ending of operations, and arcs oriented with time, representing the various operations of a technology. This representation is analogous to what is described in the PERT method used for project management. In this case the events constituted by nodes are connected through oriented arcs constituting the tasks of the project. Indicating as $\boldsymbol{E}$ the set of events determining the start or/and ending of the operations and as previously with O the set of the operations we can build up a graph τ that we can call graph of the operations of the technology:

$$\tau = (E, O) \quad (5)$$

In which $\boldsymbol{E}$ represents nodes and $\boldsymbol{O}$ the oriented arcs of the graph. Differently from the model of Auerswald, Kauffman, Lobo and Shell (1998), in our model we take into account that each operation can be associated to more than one instruction as in equation (2). For example, an operation such as heating can be associated to an instruction as the final temperature but also to a specific velocity of heating. Being from equation (1) N the number of operations and from equation (3) P the total number of instructions we have:

$$P \geq N \quad (6)$$

In which N = P when each operation is characterised by only one instruction.

1.2. Technological recipes and technological space

Considering a specific technology with a set of N operations corresponding to a total of P instructions, we can define as technological recipe the specific configuration ω obtained attributing a specific value or choice to each of the P instructions. The set Ω of all the possible configurations of a technology is given by:

$$\Omega = S_{11} \times S_{12} \times ... \times S_{1M_1} \times ... \times S_{NM_N} \quad (7)$$

In other terms we have:

$$\Omega = \{\omega_l, l = 1, ..., \prod_{i=1}^{N} \prod_{j=1}^{M_i} S_{ij}\} \quad (8)$$

The number of configurations $|\Omega|$ will be given by:

$$|\Omega| = \prod_{i=1}^{N} \prod_{j=1}^{M_i} S_{ij} \quad (9)$$

Should be $S_{ij} = S$, $i = 1, \ldots, N$ and $j = 1, \ldots, M_i$ we have:

$$|\Omega| = S^P \quad (10)$$

We may note that the number of configurations varies exponentially along with the number of values or choices for the instructions and even with a small number of instructions the number of technological recipes remains very high.

In order to better explain the previous equations we may illustrate a simple example considering a technology with the number of operations N = 2 and then:

$$O = \{o_1 , o_2\}$$

Should for example operation o_1 a heating and operation o_2 a cooling we have:

$$M_1 = \{p_{11} , p_{12}\}$$

Where the operation of heating is associated to $M_1 = 2$ instructions such as p_{11} as the final temperature and p_{12} as the velocity of heating. At the same for the operation o_2 of cooling we may have:

$$M_2 = \{p_{21}\}$$

Corresponding to a free cooling to a final temperature indicated by instruction p_{21}. Now considering there are two possible heating temperatures and only one value of velocity of heating we have:

$$S_{11} = \{s_{111} , s_{112}\} \ ; \ S_{11} = 2$$

$$S_{12} = \{s_{121}\} \ ; \ S_{12} = 1$$

At the same time should be two the final cooling temperatures we have:

$$S_{21} = \{s_{211} , s_{212}\} \ ; \ S_{21} = 2$$

The number of configurations ω present in the set Ω will be four:

$$|\Omega| = S_{11}.S_{12}.S_{21} = 2.1.2 = 4$$

These configurations or technological recipes may be represented as:

$$\omega_1 = (s_{111} \ s_{121} \ s_{211})$$
$$\omega_2 = (s_{111} \ s_{121} \ s_{212})$$
$$\omega_3 = (s_{112} \ s_{121} \ s_{211})$$
$$\omega_4 = (s_{112} \ s_{121} \ s_{212})$$

We may also define a Hamming distance d among the recipes as the minimum number of substitutions to be made to transform a recipe ω into ω'. This operation is symmetric and we have:

$$d\ (\omega, \omega') = d\ (\omega', \omega) \quad (8)$$

In the same manner we may define the set N_δ of neighbours of a recipes $\omega \in \boldsymbol{\Omega}$ defined as the number of configurations ω' existing at distance δ from ω as follows:

$$N_\delta(\omega) = \{\omega' \in \Omega \mid d\ (\omega, \omega') = \delta\} \quad (9)$$

The space in which it is possible to represent all the technological recipes through the reciprocal Hamming distance can be called technological space. The dimensionality of this space is given by number of neighbours $|N_\delta|$ for distance $\delta = 1$. Considering that each of the P instructions is characterised by S_{ij} values or choices the dimensionality of the technological space will be:

$$|N_{\delta=1}| = \sum_{i=1}^{N} \sum_{j=1}^{M_i} (S_{ij} - 1) \quad (10)$$

Should the instructions have all the same number S of values or choices the dimensionality of the technological space will become:

$$|N_{\delta=1}| = (S - 1)P \quad (11)$$

In this case the geometrical representation of the technological space becomes a hypercube of dimension $|N_{\delta=1}|$.

1.3. Efficiency of technologies and technology landscape

Technology efficiency is a complex concept that is difficult to define quantitatively in univocal terms. Technology efficiency can be measured quantitatively only defining one of its specific aspects. For example one of the most important types of technology efficiency is related to economy efficiency that can be measured as the inverse of unitary cost of production, but it is possible to consider many other types of measurable technology efficiencies such as energy efficiency, accuracy, chemical purity, amount of abated pollutants for environmental efficiency. The relations existing among the various types of efficiency are important and that is true in particular between economic and technical efficiencies such as energy efficiency, accuracy, chemical purity, etc. It is evident that the efficiency of a technology depends on the considered technological recipe. Certain recipes may have practically zero efficiency but other recipes may have high efficiency and constitute an optimum. As previously reported by Kauffmam, Lobo and Macready (1998), associating to all recipes of the technological space the corresponding value of efficiency we obtain the mapping of this space. Indicating with Θ the corresponding value of efficiency to a specific recipe ω_l of set Ω we have:

$$\Theta : \omega \in \Omega \rightarrow R^+ \quad (14)$$

This mapped space has the nature of a fitness landscape and it is called technology landscape and it depends on the specific structure of operations and instructions constituting a technology. Exploring a technological landscape we will find regions with recipes with nearly zero efficiency and other regions with recipes with high values up to optimum values of efficiency.

The efficiency of a specific recipe is in general a function of the efficiency of the various operations constituting the technology. Moreover the efficiency of an operation may be a function of the values or choices made for the instructions characteristic of the operation but possibly also by instructions of other operations existing in the recipe. In our model we consider convenient to define operation efficiency or inefficiency in such a manner that the sum of single operation efficiency or inefficiency constitutes respectively the global efficiency or inefficiency of the recipe. Considering for example the efficiency θ_i of operation o_i, it will depend on values or choices s_{ijk} of its instructions p_{ij} but possibly, also on values or choices of instructions of other operations o_l, $l \neq i$. The total efficiency $\Theta(\omega)$ of the technology with configuration ω composed by N operations will be given by:

$$\Theta(\omega) = \sum_{i=1}^{N} \theta_i (o_i, o_l) \quad (15)$$

This manner to calculate total efficiency of a recipe as sum of efficiency values of a single operation is easy made in the case of technical efficiency such as energy, purity, pollution abatement, etc. It should be noted that technical efficiency of operations may also be negative. For example in energy efficiency of a technology we could have only positive efficiency in one operation producing energy and negative energy efficiency in the other operations corresponding to self-consumptions as in the case existing in an energy production plant. However, considering economic efficiency of operations, it is more convenient to calculate cost (inefficiency) of the various operations so that the economic efficiency of a recipe may be calculated as the inverse of the sum of the cost of the operations representing, in fact the total cost of the recipe. Considering for example the cost (inefficiency) c_i of operation o_i, it will depend on values or choices s_{ijk} of its instructions p_{ij} but possibly also on values or choices of instructions of other operations o_l, $l \neq i$. The total economic efficiency $\Theta(\omega)$ of the technology with configuration ω composed by N operations will be given by:

$$\Theta(\omega) = 1 / \sum_{i=1}^{N} c_i (o_i, o_l) \quad (16)$$

And the total cost C of the recipe:

$$C(\omega) = \sum_{i=1}^{N} c_i (o_i, o_l) \quad (17)$$

It should be noted that Kauffman, Lobo and Macready (1989) in their technology model adopt a different definition of efficiency of a recipe as average of the sum of efficiency of the single operations according their use of an NK model.

1.4. Family of technologies and space of technologies

Technological space is useful to describe a single technology with defined operations structure representing all the configurations or recipes that this technology can assume following its model. When discussing of various technologies, for example studying technological competition and evolution, it may be useful to have a representation space of technologies. This representation can be obtained considering a family of technologies able to fulfil a same specific human purpose. In order to describe a space of a family of technologies it is necessary to define a distance among the various technologies taken in consideration. Technologies cannot be described by a simple combination of operations because they also have a time-oriented structure that can be represented in a graph. Because of the fact that there is a strict correlation between graphs and matrices, each technology may have its own matrix representation. That leads to define distances among technologies in terms of distances among matrices.

Let us consider a set (family) of technologies *T* involved to fulfil a human purpose, for example writing, transportation, etc. Each technology belonging to *T* is characterised by M operations chosen from a set *O* of N different operations. It means that the same operations may be in certain cases repeated in the graph structure of a technology. Furthermore, some of the N operations can be also performed “in parallel” i.e. at the same time. Every technology $\tau \in T$ can be, hence, associated with a M × N matrix T whose elements, T_{ij}, can assume either the value 1 or 0. More precisely, $T_{ij} = 1$ if the jth operations is present in the M position on the graph g related to τ, otherwise $T_{ij} = 0$. At this point it is possible to establish a Hamming distance between any pair of technologies τ and τ' in *T* as the "difference" between their matrices T and T':

$$d(\tau, \tau') = \sum_{i=1}^{M} \sum_{j=1}^{N} \left| T_{ij} - T'_{ij} \right| \quad (12)$$

By knowing all distances among the technologies of the family *T* we may build up, as in the case of technological recipes, a space that we could name space of technologies. Furthermore, it is possible to define a set N_δ of neighbouring technologies of the set *T* that are at the distance δ as:

$$N_\delta(\tau) = \{ \tau' \in T \mid d(\tau, \tau') = \delta \} \quad (13)$$

The number of all the technologies τ present in a given family *T* is not univocally determined because it depends both on the type and on the "parallel" compatibility of the N operations. If, for instance, none of the N operations could be performed at the same time as another one in *O*, the cardinality of *T* would be simply given by N^M.

In such defined space of technologies the Hamming distance between two technologies defines the degree of radicality characterizing the difference between the two technologies. In other words technologies that are at a short Hamming distance may be considered, in the time sequence of their entering in use, as evolutive or incremental innovations while technologies that are at a long distance in this space may be considered as drastic or radical innovations using the definitions of innovation proposed by previous authors such as Nelson and Winter (1977) and Dosi (1982). The path in this space that starts form an initial technology and continues through incremental and eventually radical technologies is a representation of the evolution of the initial technology.

1.5. Technology dynamics and intranality and externality of a technology

In the previous paragraph we have seen that efficiency of an operation may be influenced not only by specific instructions of the operation but also by instruction of other operations of the recipe. This fact is defined as intranality of a technology. Such interaction has been already considered in technology landscapes by Auerswald, Kauffman, Lobo and Shell (1998) and Kauffman, Lobo and Macready (1998) and studied using a NK model of interactions. However in our model, differently of model described by Auerswald, Kauffman, Lobo and Shell, we consider the possibility to have more than one instruction for each operation and when studying intranality in our model we should make reference to a generalised NK model as developed by Altenberg (1996).

Operations efficiency as well as technology efficiency can be also influenced by external factors or variables that constitute the externality of the technology and that should be taken account in our model. External variables may be constituted for example by raw materials characteristics, differences in type or composition of used products, various requirements in quality or types of certifications that production should satisfy, etc. As it has been previously done in the case of values or choices for instructions we may take in considerations various parameters for external variables forming specific external configurations in which the technology should operate. Consider the set *V* composed by B external variables v_i :

$$V = \{v_i, i = 1, ..., B\} \quad (18)$$

Each external variable v_i is characterised by a set R_i of R_i specific parameters:

$$\mathcal{R}_i = \{q_{ij},\ i = 1, .., B\ ;\ j = 1, \ldots, R_i\} \quad (19)$$

In which q_{ij} represents the jth parameter associated with the ith external variable v_i. The total number Q of parameters characterising an externality is given by:

$$Q = \sum_{i=1}^{B} R_i \quad (20)$$

The parameter q_{ij} may assume a set $\mathcal{F}_{ij}$ of values or choices :

$$\mathcal{F}_{ij} = \{f_{ijk},\ i = 1, ..., B\ ;\ j = 1, \ldots, R_i\ ;\ k = 1, \ldots, F_{ij}\} \quad (21)$$

In which F_{ij} indicates the cardinality of the set $\mathcal{F}_{ij}$.

Considering a specific externality with a set of B variables corresponding to a total of Q parameters, we can define as specific externality the specific configuration γ obtained attributing a specific value or choice to each of the Q parameters. The set Γ of all the possible configurations of an externality is given by:

$$\Gamma = \mathcal{F}_{11} \times \mathcal{F}_{12} \times \ldots \times \mathcal{F}_{1R1} \times \ldots \times \mathcal{F}_{BRB} \quad (22)$$

In other terms we have:

$$\Gamma = \{\gamma_l,\ l = 1, ..., \prod_{i=1}^{B} \prod_{j=1}^{R_i} F_{ij}\} \quad (23)$$

The number of configurations $|\Gamma|$ will be given by:

$$|\Gamma| = \prod_{i=1}^{B} \prod_{j=1}^{R_i} F_{ij} \quad (24)$$

Should be $F_{ij} = F$, $i = 1, \ldots, B$ et $j = 1, \ldots, R_i$ we have:

$$|\Gamma| = F^R \quad (25)$$

We may note that the number of configurations of external variables also corresponds to the number of technology landscapes existing for the technology operating under the influence of a defined configuration of external variables. Finally it is important to consider the value G resulting by:

$$G = |\Gamma| * |\Omega| \quad (26)$$

In which $|\Omega|$ represents the number of possible recipes existing in a technology landscape and $|\Gamma|$ the number of externality configurations generated by external variables. Then G represents all the possible global configurations of a technology that takes into account both of the number of possible recipes and of the number of configurations of external variables that influence the efficiency of technology. We may easily represent the intranality and externality of a technology by building up a matrix constituted by columns representing all the operations o_j, i=1 to N of a technology and rows representing all the instructions p_{ijk} $i = 1, \ldots, N$ and $j = 1, \ldots, M_i$ of the technology and all considered external parameters q_{ij}, $i = 1, .., B$ and $j = 1, …, R_i$ then assuming for each position a value of 1 whether influence of the specific instruction or external variable on the efficiency of the specific operation exists or 0 otherwise:

$$\begin{array}{ll}
 & o_1 \quad o_2 \quad \ldots\ldots\ o_N \\
p_{11} & \ldots\ldots\ldots\ldots\ldots\ldots \\
p_{12} & \ldots\ldots\ldots\ldots\ldots\ldots \\
 & \ldots\ldots\ldots\ldots\ldots\ldots \\
p_{NMN} & \ldots\ldots\ldots\ldots\ldots\ldots \\
q_{11} & \ldots\ldots\ldots\ldots\ldots\ldots \\
q_{12} & \ldots\ldots\ldots\ldots\ldots\ldots \\
 & \ldots\ldots\ldots\ldots\ldots\ldots \\
q_{BRB} & \ldots\ldots\ldots\ldots\ldots\ldots
\end{array}$$

This matrix corresponds to a simplified adjacent matrix of a tri-parted graph constituted by the subset of instructions, the subset of external parameters and the subset of operations with arcs that are oriented exclusively from instructions and external parameters nodes to operations nodes. This graph represents the global interactions existing for a technology. Graph may appear completely connected or in form of clusters playing an important role in modelling a technology and designing exploration of correspondent technology landscapes.

1.6. Technology innovation

It is quite common to consider research & development activities (R&D) in technology innovation in term of research phases consisting in basic oriented research generating new ideas for technology innovation, followed by applied research, normally at a laboratory stage, and, in the case of successful results in an industrial development stage normally working on pilot plants or testing prototypes that finally make the innovation possibly suitable for industrial application. This view of research & development and technology innovation has been proposed by OCDE (Freeman 1974) and is generally accepted but its linear description of the process is a quite simplified way to consider the complex process of R&D. Furthermore, the role of scientific contributions is not limited to the initial phase of the process but in the reality these contributions may exist at any phase of the development of the innovation. Finally we should consider that R&D activities are not alone in the process of technology innovation but learning by doing and adaptation of other existing technologies may play an important role in the process.

Our model suggests a completely different approach to explain the technology innovation process using concepts such as the space of technologies and the technology landscape. In fact the activity of development of an innovation may be considered an exploration of a space of technologies and technology landscape to the research for optimal conditions to establish and operate the new technology. The innovation process may be considered mainly composed by two types of activities: at the beginning research & development consisting prevalently in exploration of technology space to the search for optimal operations structure followed by learning by doing on the industrial application consisting prevalently in searching for optimal instructions in the landscape of the technology. In fact in this approach both R&D and learning by doing activities are parts of the same model and may be seen from a common point of view. In this way technology assume a dynamic in its process of innovation starting from research & development to the industrialisation phase and continuing through the learning by doing activity along the entire life of a technology until reaching an obsolete stage in which the technology is abandoned in favour of more efficient technologies.

2. APPLICATION OF THE MODEL

In the tap & valve industry there is a problem concerning the contamination of drinking water by lead contained in the brass alloys used to make taps & valve. In order to comply with environmental norms it is necessary to eliminate lead from the surface of brass using a specific leaching technology. On the other side there is the problem to optimize the conditions of the treatment in order to decrease the cost but at the same time the complying of norm specifications. Such work requires a great number of experiments to identify the values of parameters of the technology that can satisfy such requirements as a function of costs (economical efficiency) and reached decontamination levels (environmental efficiency). Using the fitness landscape of the technology and its intranality and externality aspects, the model allows the establishment of an effective plan that minimizes the number of experiments that are necessary to identify the optimal conditions of treatment.

2.1. Modeling of RUVECO® technology

RUVECO® technology is one of the used technologies to eliminate lead from the surface of brass (Bonomi A. Carrera S. Franzosi G. 2001) and consists of three main technological operations in sequence in three different treatment baths as reported in Fig. 6 and indicated as follows:

Operation A: degreasing of parts by a suitable agent
Operation B: selective elimination of lead from surface of pieces parts by suitable agent
Operation C: neutralisation by sweeping off residual bath from the parts

In the Table 3 we have reported the various considered instructions related to the three operations of the technology

Table 3. Operations and instructions implied by RUVECO® technology

Operations	Instructions	Instruction symbol
Degreasing	Temperature	A-1
	Time	A-2
	Degreasing agent concentration	A-3
De-leading	Temperature	B-4
	Time	B-5
	De-leading agent concentration	B-6
	Bath stirring	B-7
	Positioning of components	B-8
Neutralization	Time	C-9

In Table 4 we have reported the selected values for instructions implied in the operations calculating s as the number of values or choices for each instruction:

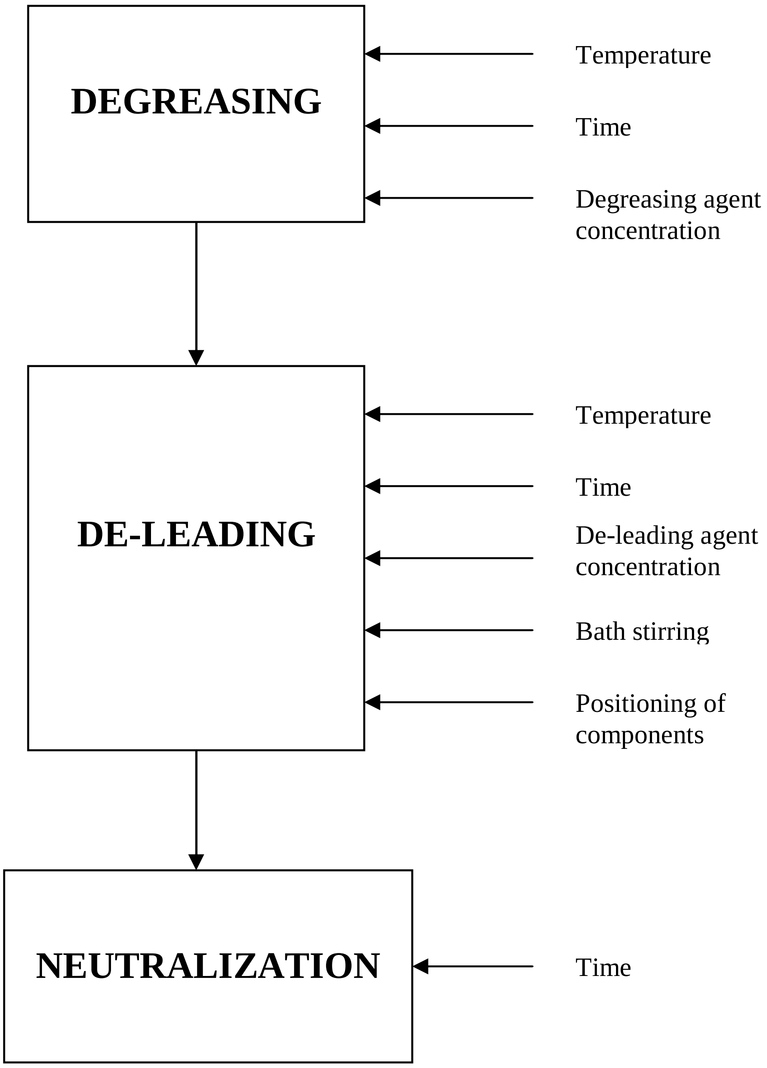

Fig. 6. Schematic view of RUVECO® technological operations and instructions

Table 4. Number s of values or choices for instructions

Instruction	Values or choices	s
A-1	2 temperatures (40° and 50°C)	2
A-2	2 times (5 and 10 minutes)	2
A-3	2 degreasing agent concentrations (high and low)	2
B-4	2 temperatures (40° and 50°C)	2
B-5	5 times (5, 10, 15, 20, 30 minutes)	5
B-6	2 de-leading agent concentrations (high and low)	2
B-7	2 levels of bath stirring (strong and medium)	2
B-8	2 possible positioning of components	2
C-9	2 duration of neutralisation (long and short)	2

The number of recipes of the technological space corresponding to the chosen range of instructions may be easily calculated using equation (9) reported in Chapter 1 of this appendix:

$$| \Omega | = 2*2*2*2*5*2*2*2*2 = 2^8*5 = 1280 \quad (1)$$

It is also interesting to consider the intranality of the technology that is represented in Table 5 in which the existing interactions between instructions and operations are indicated by a cross.

Table 5. Intranality of RUVECO® technology

Instruction	Operations		
	Degreasing (A)	Deleading (B)	Neutralisation (C)
A-1	X	X	
A-2	X	X	X
A-3	X	X	X
B-1		X	X
B-2		X	X
B-3		X	X
B4		X	X
B-5		X	X
B-6		X	X
B-7		X	X
B-8		X	X
C-9			X

In addition we should also consider some important externalities of the technology that may be composed by four external variables, each characterized in our case by only one parameter that may influence the process:

Variable V-1: Brass composition
Variable V-2: Fabrication (wrought or cast component)
Variable V-3: Form of the component
Variable V-4: Certification (maximum allowed lead contamination)

Choices made for external variables are reported in Table 6 indicating with f the number of values or choices.

Table 6. Values or choices of external variables

External variable	Values or choices	f
V-1	3 alloy compositions	3
V-2	2 types of fabrications (wrought or cast component)	2
V-3	2 types of geometry (simple or complex)	2
V-4	2 types of certifications (easy or difficult)	2

The number of externalities configurations may be easily calculated by use of equation (24) reported in Chapter 1 of this appendix and data of Table 6:

$$|\mathit{\Gamma}| = 3*2*2*2 = 24 \quad (2)$$

There are 24 externality configurations corresponding to 24 possible technological landscape configurations for each type of efficiency under consideration. The various external configurations will also influence efficiency of operation and this externality is represented in Table 7 by indicating the existence of an interaction by a cross.

Table 7. Externality of RUVECO® technology

External variable	Operations		
	Degreasing (A)	Deleading (B)	Neutralisation (C)
V-1		X	
V-2	X	X	
V-3	X	X	
V-4		X	

Adopting such model of technology it is possible to calculate the total number of positions existing in the 24 possible technological landscape configurations by using equation (26) of Chapter 1 of this appendix and values of equations (1) and (2):

$$G = |\mathit{\Omega}|*|\mathit{\Gamma}| = 1280*24 = 30720 \quad (3)$$

That gives a total of 30720 measurements of efficiency to take account of all 24 configurations of the technological landscape.

2.2. Simplification of the model

We have seen previously that complete characterisation of the 12 technological landscape needs a very high number of efficiency measurements. This number can be reduced by introducing some reasonable simplifications in the model. These simplifications should take account of parameters and interactions that might have a limited or negligible influence on the efficiency of the technology from the scientific or technical point of view. In this way we make a sort of mapping of the landscape isolating a limited region that could probably contain the optimal working conditions and be characterized by a much lower number of positions. In the case of RUVECO® technology we may consider that efficiency of degreasing and neutralisation operations are essentially dependent only on time using standard temperature and concentrations of the agents. On the other side the efficiency of the de-leading operations may be essentially dependent on temperature, time and de-leading agent concentrations neglecting bath stirring and system of positioning in the bath. Looking to instructions of Table 4 and simplifying them as cited previously, the number of recipes becomes:

$$|\Omega| = 2*2*2*2*5 = 2^4*5 = 80 \quad (4)$$

Also external variables may be simplified not taking in consideration geometry of the part and testing only the most difficult certification for determining the set of recipes complying with its standard. Adopting these simplifications in variables of Table 6 the number of external configurations becomes:

$$|\Gamma| = 3*2 = 6 \quad (5)$$

That means the total number of measurements to characterise the six configurations of the technological landscape are:

$$G = |\Omega|*|\Gamma| = 80*6 = 480 \quad (6)$$

Finally the intranality and externality of the technology may be described by integrating data of Tables 5 and 7 and adopting the cited simplifications. The interactions obtained are reported by a cross in Table 8.

Table 8. Intranality and externality of RUVECO® technology in the simplified model

Instruction/Variable	Operations		
	Degreasing (A)	De-leading (B)	Neutralisation (C)
A-2	X	X	
B-4		X	X
B-5		X	X
B-6		X	X
C-9		X	X
V-1		X	
V-2		X	

Concluding, following the simplified model the design of experiments will consider the measurement of de-leading efficiency of 80 recipes in 6 different external configurations for a total of 480 measurement, and calculation of economic efficiency (cost) of the 80 recipes. The obtained de-leaded samples will be submitted to verification of their acceptability following the selected certification determining the set of recipes complying with this standard. Comparing the cost of treatments of the set of complying recipes for each configuration it will possible to choose the more efficient recipe for each external configuration that will correspond to the recipe with the lowest cost. The knowledge of optimal treatment recipes, as a function of the various characteristics of the part that should be de-leaded, will determine reliable conditions for establishing a quality assurance program in the use of the technology.

REFERENCES

Altenberg L. 1996, *NK Fitness Landscape*, Section B2.7.2 in The Handbook of Evolutionary Computation, ed. T. Back, D, Fogel, Z. Michalewicz, Oxford University Press, 1997

Arthur B. 2005 *The Logic of Invention*, Santa Fe Institute Working Paper 05-12-045, December 19, 2005

Arthur B. 2009, *The Nature of Technology*, Free Press, New York

Auerswald P. Kauffman S. Lobo J. Shell K. 1998, *The Production Recipe Approach to Modeling Technology Innovation: An Application to Learning by Doing*, Santa Fe Institute Working Paper 98-11-100. Published on Journal of Economic Dynamics and Control, 2000, 24, 389-450

Bonomi A. Haour G. 1993, *L'innovation technologique et sa promotion dans la petite et moyenne enterprise*, Le Progrés Technique, 3, 43-48

Bonomi A. Carrera S. Franzosi G. 2001, *Selective de-leading process and bath for plumbing components made of a copper alloy*, US Patent 6,284,053B1

Bonomi A. Marenco P. 2006, *Cooperative Technological Development in Italian Industrial Districts*, Workshop on Perspectives for districts and scientific and technological parks. The role of marketing.. University of Genoa, Faculty of Economic Science, April 7, 2006, available as publication on site www.complexitec.org in the Technology Innovation section

Bonomi A. Riu A. Marchiso M. 2007, *Modelling Technologies for Experimental Planning*, Working document available on site www.complexity.org Education and Research section.

Bonomi A. Castellero A. Ricchiardi G. 2008, *Indagine preliminare sui bisogni di innovazione tecnologica e possibilità di cooperazione nel distretto del casalingo nel Cusio*, Report available on site www.complexitec.org in the Technology Innovation section

Bonomi A. 2010, *A Simple Model of R&D Activity and Implications in Technology Development of a Territory*, available on site www.complexitec.org in the Technology Innovation section. Presented for publication on the World Review of Science, Technology and Sustainable Development.

Bonomi A. 2011a, *Bottom up Approach to Cooperation in Technology Innovation*, Working document available on site www.complexitec.org in the Technology Innovation section

Bonomi A. 2011b, *Use of a Model of Technology to Generate Technology Innovation Projects for SMEs*, Working document available on site www.complexitec.org in the Technology Innovation section

Bonomi A. Rolfo S. 2012, *Coopération pour l'innovation à niveau local: un exemple italien de succes*, Colloque ASRDLF, Belfort 10 juillet 2012, available as publication on site www.complexitec.org in the Technology Innovation section

Branscomb L. Morse K. Roberts M. Boville D. 2000, *Managing Technical Risks*, NIST GCR 00-787

Dumbleton J.H. 1986, *Management of High Technology Research and Development*, Elsevier Science Publisher

Dosi G. 1982, *Technological Paradigms and Technological Trajectories, A suggested interpretation of determinants and direction of technical change*, Research Policy, 11,147-162

Fleming L. Sorensen O. 2004, *Science as a map in technological search,* Strategic Management Journal, 25, 908-928

Freeman C. 1974, *The Economics of Industrial Innovation*, Penguin, Harmondsworth (OECD Report: The Measurement of Scientific and Technical Activity)

Frenken K. 2001, *Understanding Product Innovation using Complex Systems Theory*, Academic Thesis, University of Amsterdam jointly Université Pierre Mendés France, Genoble.

Garnier J. 2008, *Des anciens tissues productifs aux nouveaux clusters: quelle transition ?* L'Hartmattan

Kauffman S. Lobo J. Macready W. 1998, *Optimal Search on a Technology Landscape,* Santa Fe Institute Working Paper, 98-10-091E, October 10, 1998 Published on Journal of Economic Behaviour and Organization, 2000, 43, 141-166

Nelson R.R., Winter S.G. 1977, *An Evolutionary Theory of Economic Change*, Cambridge MA & London: Belknap Press of Harvard University Press

Waldrop M. 1992, Discussions between Brian Arthur and Stuart Kauffman in Chapter III of *Complexity, The emerging science at the edge of order and chaos*, Simon & Schuster, New York