Use of a Model of Technology to Generate Technology Innovation Projects for SMEs

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1. INTRODUCTION

It is well known that SMEs have difficulties in developing technology innovation especially when confronted with R&D activities concerning radical innovations. Most of technological innovations made by SMEs are incremental, mainly obtained by learning by doing, and have a limited impact on increase of competitiveness due to the well known red queen regime. In such regime competitive advantages are easily destroyed by reaction of competitors that have similar competences and success in innovation. Major threats are present especially in SMEs producing conventional products with a high level of export competing in global markets. That is the typical case of Italian SMEs producing the same type of products and clustered locally in industrial districts. Such firms give the major contribution in exporting the typical “Made in Italy” products and have normally a highly competitive technological level. However their technology evolves practically only in term of incremental innovations due to the difficulties to make adequate R&D efforts as cited previously. Such situation may have dangerous consequences in the medium and even short term as competing industries in emerging countries are able to reduce continuously the existing technological gap taking advantages by other economical factors existing in such countries. Furthermore it cannot be excluded the appearing of foreign radical technological innovations that destroy competitiveness in companies owing only conventional technologies and making traditional products. There is some example in the past of such situation of rising competition from emerging countries and appearing of radical innovation as the case of threat occurring to Swiss watch industry in the seventies of the past century by low cost mechanical watches produced in South East Asia and the radical digital electronic watches introduced by Japan.

One of the important obstacle opposing to technological innovation with some radical character in SMEs is the generation of adequate R&D projects. Differently form large industry, SMEs do not carry out systematically technical and scientific studies, as well as patent intelligence and market studies, to identify the most suitable technological innovations to develop. On the other side a single SME is rarely in condition to make such effort and cooperation with other SMEs may be a valid issue. We think that cooperation of SMEs, enabling radical innovations developed in the frame of a common strategy concerning the use of technology innovation as a major competitive factor, is probably the sole way for SMEs to remain competitive in the medium and long term faced to the challenges of globalization of production and markets. Identification of technological innovation with some radical character for SMEs presents some specific aspects and in this work we try to present an approach to this problem using a simple model of technology based on the fact that innovation may be seen as the result of combinatory work of existing technologies enabling to exploit new physical phenomena or properties of matter leading to possible radical innovations. In order to explain the method we give an example of application in identifying possible technological innovations in the traditional production of taps & valves and that of metallic households confronted with the potential radical innovations that could come from nanotechnologies.

We start the work in the second chapter describing a model of technology based on a structured ensemble of technological operations each characterized by a set of parameters and choices. We explain as such operational ensemble is subjected to the influence of various type of externalities and that modification of the nature or parameters of an operation may have influence on the other existing operations as effect of what is called the intranality of a technology. Technology innovation may be seen as an exploration in searching optimal conditions and radical innovations may be seen as the result of new combinations of preexisting technologies that modify sensibly the operation structure of a technology. In the third chapter we explain the operational structure of two examples of technologies concerning the production of taps & valves and of metallic household. We discuss the various types of externalities existing for such technologies and potential interesting fields for radical innovations as well as the intranality effects on the technology. In the fourth chapter we examine the field of nanotechnologies either in term of technologies or as new available phenomena or properties of matter trying to connect such possibilities with new radical innovations potentially existing for conventional products. Finally, in the conclusion, we present the most interesting aspects and limitations of our approach in identifying technology innovations of radical character.

2. MODEL OF TECHNOLOGY AND TECHNOLOGY INNOVATION

A general description of technology independently of either specific technical or socio-economic aspects is useful for our purposes and may be carried out using a general model able to describe any type of technology. In fact there are two approaches to modeling. One considers technology as an artifact composed by various components each with its characteristics, for example a car is composed by a motor, brakes, tires, etc. and the relation among the various components may be studied in order to optimize choices and characteristics. Such modeling approach has been studied for example in a thesis work (Frenken K. 2001). Another approach, more useful for our purposes, considers technology as a structured ensemble of technological operations each characterized by a set of parameters and choices. For example considering a technology for heat treatment you may have an operation of heating to a certain temperature at a certain rate of increasing temperature with time, an operation of maintaining in temperature for a certain time, and a cooling operation at a certain dropping rate of temperature. Such approach has been introduced to explain technology innovation made by learning by doing (Auerswald P. Kauffman S. Lobo J. Shell K. 1998) and to reproduce the typical engineering experience curves expressed by empirical laws (Wright T. P. 1936). In the structure technological operations may be connected in sequence or in parallel with time in a similar way as tasks are connected in the well known PERT method used in project management. In Figs. 1 and 2 we have reported two examples of operation structures respectively for technology of production of taps & valves and production of households considered in this study. In this model a technology is defined by the structure and types of operations and, should exists some difference in operations (elimination, substitution, addition) or structure, the technology should be considered different. On the other side all technologies fulfilling the same human purpose (Arthur B. 2005) may be considered belonging to the same family of technologies. In this model of technology the elaboration of the structure of the operations results more or less complex depending on details we want to use for the model. For example considering the technology of production of taps whose structure of operations is presented in Fig. 1, chromium plating of taps may be considered itself a technology and may be structured in terms of sub-operations composed in this case by cleaning taps, plating a layer of nickel, coating the nickel deposit by a thin layer of chromium and finally washing the treated tap. In other words the terms of technology and technology operation are interchangeable depending on how a technology is detailed and both have consequently the same nature. There is a further aspect in defining the scope of the model that takes in consideration the fact that practically all technologies are linked in what it could be called a technological ecosystem (Waldrop M. 1992).

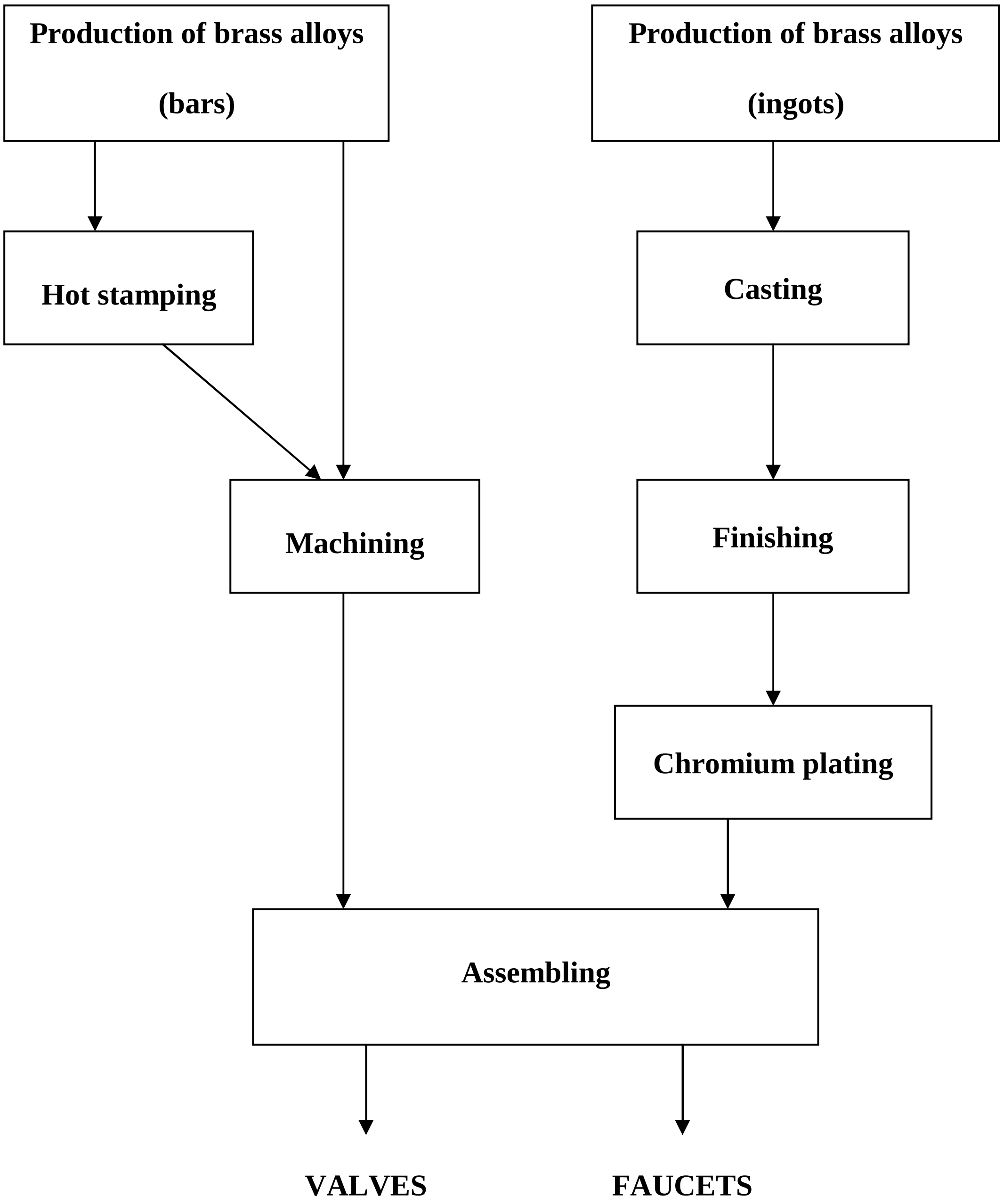

Fig.1. Technological structure of operations in production of valves and faucets

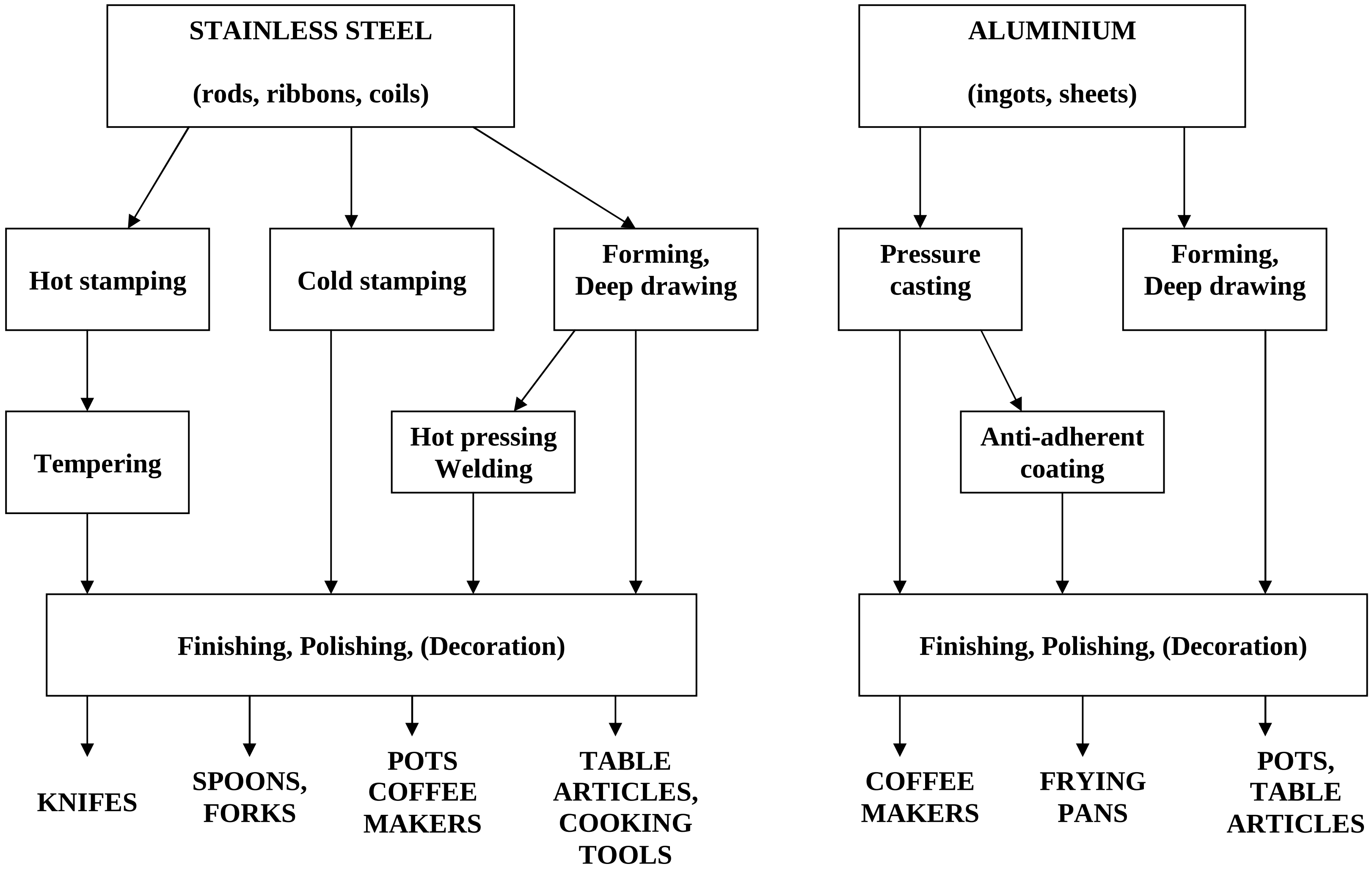

Fig.2. Technological structure of operations in production of metallic households

An established model of a technology is then a function of the portion of the technological ecosystem you want consider. For example in production of valves, as reported in Fig. 1, you can limit your model simply to technology of hot stamping or extend the structure also to the production of brass alloys bars. Concluding the model takes account of the various aspect of use of the term technology that generally may indicate the ensemble of all existing technologies, families of technologies fulfilling the same specific human purpose, technology as a specific set of technological operations and portion of the technological ecosystem you want to consider for the model purpose. Finally technological operations may be considered technologies whereas technologies considered operations depending on the gross or fine grain structure adopted for the model.

Another important aspect of technologies is their efficiency that pilots directly or indirectly the evolution of use of technologies. From the quantitative point of view a technology efficiency may be measured not by only defining the operation structure of the technology but it is necessary to consider the various values of parameters and choices that characterize what it may be called the configuration or recipe of the technology. On the other side there are many types of efficiencies that may be defined for a technology. An important efficiency is of course the economic efficiency that may be represented for example by a relation with the unit cost of production characterizing a specific recipe of a technology, but there are many other types of definitions for technology efficiency such as for example energy efficiency or environmental efficiencies in term of reduction of pollutants, etc. The choice of the type of efficiency that should be considered will depends of course on the purpose taken in account in studying a technology. It is possible to consider not only the efficiency of a technology but also the efficiency of a single operation that has, as noted previously, the nature of a technology. In certain case it is possible to define the efficiency of an operation in such a way that the efficiency of the technology results the sum of the efficiency of the various operations constituting the technology. For example, defining an economic efficiency related to the unit cost of production, the economic efficiency of a technology is the result of the sum of the economic efficiencies of the various operations.

Further aspects of the considered model of technology are represented by the so-called externalities and intranalities of a technology and play an important role in technology innovations. Externalities of a technology represent all the factors of the technological ecosystem that interact with the technology and are represented for example by change in composition of used raw materials or semi-products, availability of new materials or apparatus such as sensors or microelectronic devices as well as new norms regulating security or economic, market, social and environmental aspects of the product or the production process. Intranalities of a technology represent the influence of changes in parameters or choices for an operation or even changes of structure of operations have on the efficiency of the other operations of the technology and consequently on the global efficiency of a technology. This effect is well known when introducing changes in technology operations it results often the necessity to change parameters of other operations or even the structure of operations to maintain the efficiency or obtain the expected increase of efficiency for the technology.

The model of technology discussed allows also a mathematical description. Such approach has been developed for studying learning by doing to reproduce the well known engineering curves (Auerswald P. Kauffman S. Lobo J. Shell K. 1998) statistically represented by the Wright law (Wright T. P. 1936). In such approach a technology is considered a set of operations each characterized by choices and parameters that assume various discrete values in an established range. In such a way it is possible to describe a technology in terms of its operations with their specific values for parameter and choices constituting configurations or recipes of the technology. The set of all possible configurations of a technology may be represented by a point in a multidimensional graph in which the position of points is fixed by using the Hamming distance as defined in the code theory. That means more a recipe is different from another, higher will be the Hamming distance between the two recipes. This representation is called *technological space* and it is valid for any specific operations structure of a technology. For any point of the graph representing a specific configuration or recipe we may associate a scalar value representing the efficiency of technology in such configuration. We obtain in this case a fitness landscape of the technology that is called the *technological landscape* correspondent to the technological space. It can be shown mathematically that if variation of efficiency of an operation does not affect the efficiencies of the other operations, meaning that intranality effects are absent, the landscape is monotonous and presents only one recipe with a "peak" of optimal efficiency, otherwise the landscape will present numerous "peaks" with different heights of efficiency forming a rugged landscape. It is interesting to note that the activity of learning by doing searching optimal conditions for the operations of a technology may be considered as an exploration of the technological landscape in order to find a recipe with a suitable peak of efficiency. Applications of such mathematical model have been found in defining optimal searching methods (Kauffman S. Lobo J. Macready G. 1998) and in planning of experiments (Bonomi A. Riu A. Marchisio M, 2007).

Considering now an entire family of technologies fulfilling the same human purpose we can also define what it may be called a *space of technologies*. In this case it is necessary to take account of all types of operations and structure of technologies owning to the same family creating a multidimensional graph in which the points represent all the technologies of the family (Bonomi A. Riu A. Marchisio M, 2007). Also in this case more is higher the Hamming distance between two technologies more different they will be in terms of operations and structure of operations. In the case of the space of technologies it is not possible to attribute an efficiency to each point representing a technology to form a fitness landscape. In fact efficiency does not depend by the technology itself but by configuration or recipe adopted for the technology among the various available ones. However it is interesting to note that the Hamming distance between an old and a new technology in their space represents a measure of the radical character of the new technology in respect to the old one. Analogously to learning by doing, a R&D activity may be considered an exploration in the space of technologies searching a technology with an expected possible greater efficiency. Furthermore, covered claims of patents may be considered as defined parts of the technological landscape and of the technology space of the protected invention and such aspect may be useful for example in patent intelligence studies. The use of the described mathematical model of technology is not necessary for the purpose of this study, however, many concepts developed for this mathematical model are useful in the description of our approach to generation of R&D projects.

Technology innovation in this model may be divided in two types of activities one concerning learning by doing and the other one concerning R&D. Learning by doing makes innovation essentially on industrialized technologies by a prevalent exploration of the technology landscape and limited changes in terms of operations and structure of operations. For such reason learning by doing does not generate normally radical innovations in the case of the modern complex technologies. R&D makes innovation essentially by laboratory research or working on pilot plants or realizing prototypes and it has the possibility to find radical innovations exploring not only the technology landscape but also the space of technologies generating new concepts for products and production. Considering the purpose to implement competitive technology innovations with a certain radical character we may limit our study to R&D activities.

In order to develop a method for generation of radical innovation it is necessary to understand how new ideas are generated and constitute the basis of new R&D projects. The nature of technology indicates that new technologies are in fact a combination of pre-existing technologies sometimes able to exploit new phenomena or properties generating radical innovations (Arthur B. 2009). That also means that past R&D projects play an important role in generating new R&D projects. Using a model of the R&D activity it is possible to show that such combinatory view of innovation may explain failure of R&D financial support in territories with a weak techno-scientific structure unable to auto-generate a sufficient number of innovations to support a socio-economic development (Bonomi A. 2010). In this study we have chosen to consider two conventional technologies concerning respectively the production of taps & valves and that of metallic households in order to identify possible R&D projects for innovations with a certain radical character by considering the field of nanotechnologies as the source of new ideas. The method used to approach such task may include the following steps:

- Elaboration of a suitable structure of operations of the conventional technology with a suitable detail
- Identification of major existing externalities and trends affecting the technology
- Examination of the possible changes in the operations of the technology and possible new concepts of products that may affect the operation structure of the technology having a preliminary view of intranalities arising from potential changes in the technology
- Examination of potentialities of the source of new ideas of innovation in the new technology (in our case nanotechnologies) either in term of new technological operations or existence of new phenomena or properties that may be of interest for innovations
- Emergence of radical innovative ideas for the examined technology through a cross fertilization work on information collected in the study
- Identification and selection of interesting R&D projects for innovation of the conventional technology.

In Fig. 3 we have reported a schematic view of the general method used to study applications of new technologies leading to identification of R&D projects and technology innovation processes. We will show in the following chapters two practical examples of application of such method.

3. STUDY OF CONVENTIONAL TECHNOLOGIES

The schematic view of technologies for production of taps & valves and households are reported respectively in Fig. 1 and 2. Both technologies are influenced by various externalities that include search of new materials and surface treatments to improve characteristics and reduce costs and appearance of new more compelling regulations and environmental requirements. All that externalities may lead to elaboration of new concepts for the products and possibly introduction of new technologies such as microelectronic or nanotechnologies.

3.1. Technology of production of taps and valves

Traditional material used for taps and valves suitable for drinking water is brass that has a long history of use with satisfactory results. However it is presently a relatively expensive material and since many years it is considered its substitution, at least for certain parts, and plastic are the materials more considered for such substitution. An important evolution of norms influences the externalities of taps & valves production and concerns limits of level of contamination of drinking water with heavy metals especially in the case of lead, contained in the used brass alloys, and nickel, from deposits that are inevitably formed in the inner parts of taps during chromium plating operations. In the case of lead there are many possible solutions as the use of lead free brass, alternative materials not containing contaminating metals, surface layers preventing lead contamination or depleting of lead present on the surface of brass.

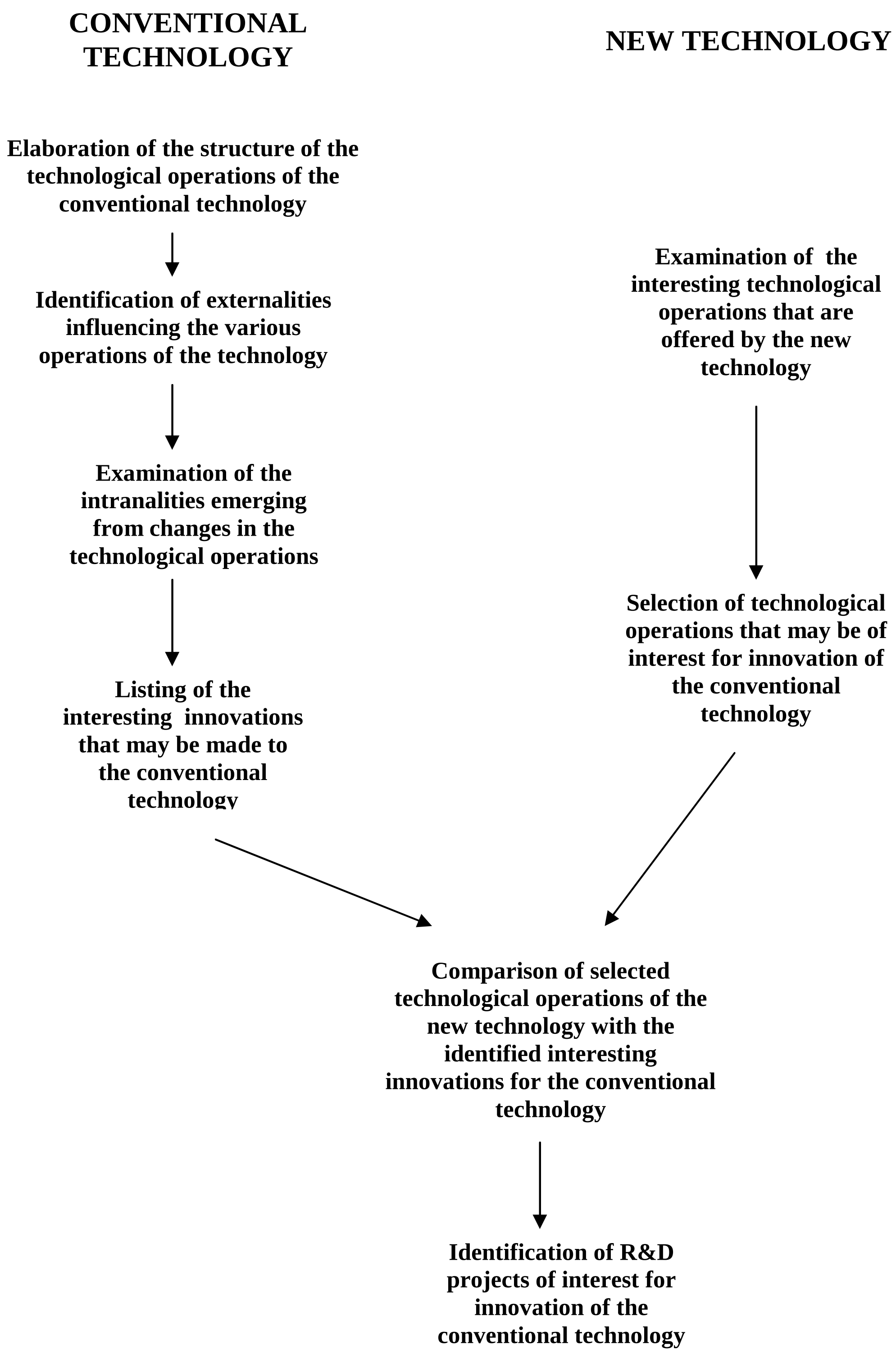

Fig. 3. View of method of identification of R&D projects for conventional technologies

All these technologies have limitations. In the case of lead free brass there is the problem of machinability of brass, surface layers may have problems of durability and lead depletion does not assure a complete absence of contamination. Another externality influencing taps is the environment problems for chromium plating. Although pollution of chromium VI used in galvanic industry may be well controlled, there is always some risks in the case of accidents. Substitution of chromium VI with other less dangerous products and a possible change of surface treatment technology may be of interest for such industry. Certain cited externalities involve important intranalities in the technology. This is the case of substitution of actual brass alloys with less expensive and more environmentally suitable materials such as lead free brass or other metals such as aluminum or steel. That involves important changes in hot stamping and machining and even substitution of present machining equipment in the case of use of other metals than brass.

3.2. Technology of production of metallic households

In the case of metallic household production we have similar externalities concerning new materials and surface treatments to improve characteristics and reduce costs, however this technology is not presently submitted to any pressing environmental norms evolution as in the case of tap & valve industry. Another important externality concerning pots and pans is the evolution of the heating systems. The use of electric heating instead of fire has lead such industry to develop special multilayer bottoms to increase thermal conductivity avoiding deformation in order to assure a perfect contact with the heating plate. A further evolution of heating system concerns the use of electrical induction. In such case the conventional stainless steel and aluminum materials used for pots and pans are not suitable and plain carbon steel should be used in the multilayer composition of the bottom to assure heating. Surface treatment technologies, either conventional galvanic treatments or physical or chemical vapor deposition treatments, are not practically used in such industry. An exception is deposition of anti-adherent layer used mainly in aluminum pans. In most cases a fluorinated polymer is used for such purpose. Such materials however is non very resistant and is slowly eroded by use, furthermore overheating of such material may produce toxic products. Such situation generate an externality for this technology looking for more resistant and biocompatible layers. It should be also noted that deposition technology of fluorinated polymers may also have environmental problems concerning gas emissions. Another important part of pots and pans is represented by handles that are generally made using plastic materials with limited resistance to temperature, That makes the need to find new suitable material that have low thermal conductivity and possibly sufficient heating resistance for use in ovens. Differently of taps & valves industry, introduction of new materials in households production generates less intranality effects. Most of used equipment such as press could be used without major changes in forming other than stainless steel or aluminum materials such as carbon steel or multilayer sheets.

4. POTENTIAL APPLICATIONS OF NANOTECHNOLOGIES

When discussing on nanotechnology it should be firstly emphasized that, as the word means, it is a technology not a science. What is true is that nanotechnologies do allow important advances in science concerning knowledge and manipulation of very small amount of matter, practically at atomic or molecular level, reveling new interesting properties and behaviors. Conventional chemistry also concerns the study of very small particles of matter such as atoms and molecules but knowledge has been based generally on properties and behavior of relatively big amounts of matter, much greater than amounts that could be studied through nanotechnologies. Very small amounts of matter do not have necessarily the same properties and behavior than macroscopic amounts treated in conventional chemistry, consequently nanotechnologies open a new way to make a new chemistry. Nanotechnologies as a new field of technology differ from other new fields such as ITC or biotechnology as they are not linked to any specific fields of industrial applications and may even find an use in such sectors. From a certain point of view biotechnology may be considered a part of nanotechnology concerning manipulation of biological active molecules. Nanotechnologies are sometimes classified in term of application fields such as engineering, chemistry and medicine, material science and physics and earth sciences (Coccia R. 2011). In other studies it has been considered the various types of industrial sectors that may be interested by nanotechnologies (Finardi U. Vitali G. 2009). However, for our purposes, such classifications are not useful and it is necessary to consider the presented general model of technology in which a nanotechnology may be viewed as a technological operation that can be integrated in a conventional technology. For this purpose we may divide nanotechnologies in two field: the first one concerning materials with nanometric dimensions either for structural or functional purposes, the other one concerning manipulation of atoms and molecules in what it could be called a molecular mechanics in which supra-molecular structures and even molecular motors are realized. The first field concerning materials appears the most interesting to face the actual externalities either for taps & valves or households technologies for which new materials and surface treatments are important. Nanometric materials may be further classified following their dimensional aspect. The simple case is of course the form of nanometric particles but we may have nanometric structures along one dimension in the case of wire, fibers or nanotubes, along two dimensions in form of layers with nanometric thickness and finally in tridimensional structures as in nano-crystalline solids formed by grains of nanometric dimension.

Looking to externalities of tap & valves and household technologies interested by new materials and surface treatments it will be necessary to examine the contribution of nanotechnology in these fields. Concerning materials nanotechnologies offer essentially two types of approaches, one concerns the formation of materials with a nanostructure such as for example nano-crystalline alloys for structural application. Another approach consists in using nano-particles in form powders, fibers, tubes, etc. as additives to conventional materials, mainly plastics, to obtain specific new properties forming what it is generally named a nano-composite material. In fact, it is well known that particles of nanometric dimension have a much different effect as charge in materials in respect to particles of greater dimension also when they have the same chemical composition In the case of surface treatments nanotechnologies may be used in many different ways. First of all it may be considered the formation of a nanometric layer covering the surface of the bulk. However in such case the thin layer is easily scratched such treatment is valid when it exists a certain form of auto-regeneration as in the case of natural passivation of certain metals and alloys when exposed to air. Another possible application of nanometric layers may be in improving adhesion between a normal layer to the surface of bulk or between two normal layers covering the bulk surface. It is also possible to use of nanometric particle as charge of a layer for structural or functional use. It is the case of use for example titanium dioxide crystals for their catalytic effect in maintaining cleaned surface or dispersions of nanometric globules containing polymerizing substances in paints to improve their resistance. Finally there are many other types of possibilities for specific nanometric structures formed on a surface. An example is the formation nano-bristles on a surface to improve adhesion as in fact occurring in nature on paws of geko. Use of nanotechnologies is of course associated with various types of technological operations. These may include techniques for the production of powders, fibers, tubes, globules of nanometric dimension, techniques for the formation of materials with nanometric structures, techniques for the dispersion of nanometric particles in materials or in surface layers as well as various techniques of deposition of nanometric layers. Considering now the cases of tap & valves and households technologies we may consider the following possible application.

Tap & valves

A major problem of such technology concerns the availability of lead and nickel free materials avoiding contamination of drinking water. Normal lead free binary brass is difficult to machine and special additions forming suitable dispersions or alloying components typically forming intergranular compounds enabling an easier machining. Nanotechnology may offer the formation of nano-crystalline structures, that however are not well known in the case of brass, or better the possibility to form intergranular nano-crystalline compounds that may favor machinability of the material. Another possibility offered by nanotechnologies concern the use of materials other than brass. For example suitable materials in form of nano-composites with improved mechanical properties, being free of contamination, may be a substitute for certain parts in brass. Finally a last alternative is constituted by a surface treatment covering the current used brass with a resistant protective layer avoiding contaminations and possibly giving other properties such as non adhesion of impurities and microbiological protection. Another important problem of tap & valves technology is substitution of the current galvanic chromium plating process that has environmental problems and is a source of nickel contamination. Also in this case nanotechnologies may be considered for a surface treatment in order to obtain a resistant layer with typical chromium plate aspect but avoiding nickel contaminations and environmental problems of present galvanic chromium plating.

Households

One of the major problem of metallic households is the cost of used materials and the fact that these do not have the whole good properties necessary for their use. For example stainless steel is a good material giving a clean aspect to households during long times of use but it has a bad thermal conductivity for heating. Aluminum has a much better thermal conductivity but the surface aspect degrades with time. Further both are not suitable for induction heating. An alternative material is low carbon steel that has good mechanical properties. It is much cheaper, especially compared to stainless steel, and has a good thermal conductivity, not high such in the case of aluminum, but much better than in the case of stainless steel. Furthermore it is well suitable for induction heating differently from the other two materials. Steel has not the same corrosion resistance and durable clean aspect as the other two materials but it is possible to consider new various types of surface coatings at the bottom and at the inner and external part of pots and pans for which nanotechnologies may offer an interesting contribute. Another problem of pots and pans are handles that may be metallic or plastic. In the first case we have a problem of high temperature during heating and in the second case the handle is not suitable for heating in oven. It will be of interest in this case to study new nano-composite materials that may have low thermal conductivity or high temperature resistance. There is also the problem of common anti-adherent coatings particularly used for the inner parts of pads. The conventional coating based on fluorinated polymers are sensible to erosion with time and when overheated may liberate dangerous compounds. An alternative coating biocompatible and possibly of mineral nature will be the best solution and nanotechnologies of surface treatments may be of interest in such research. Finally nanotechnology may offer various coloration of household products through formation of nanometric thin oxide surface layer possible when using titanium metal as substrate material.

In the Tables 1 and 2 we have reported problems and potential nanotechnology solutions respectively for tap & valves industry and metallic household industry.

TABLE 1. Potential innovations by nanotechnologies in tap & valves industries

Problem	Potential solutions by nanotechnologies
Elimination of contamination by heavy metals in brass	• New alloys based on nanostructures or by presence of intergranular nano-particles • New protective surface treatments
New non contaminant and less expensive materials	• Nano-composites substituting parts in brass
Substitution of chromium plating and elimination of nickel contamination	• New surface treatments avoiding contamination and with the same aspect of chromium plated surfaces

TABLE 2. Potential innovations by nanotechnologies in household industries

Problems	Potential solutions by nanotechnologies
New less expensive materials suitable for various types of heating	• Use of steel with adequate protection at the bottom and suitable surface treatments on the inner and external part of pots and pads
New material for handles	• Nano-composites for thermal insulation or resistance to oven temperatures
Anti-adherent deposits	• New biocompatible deposits of mineral nature with durable resistance
New esthetic aspects	• Use of titanium substrates with various colorations obtained by formation of nanometric oxide films

5. CONCLUSIONS

It should be emphasized that this work in identification of possible application of nanotechnologies in tap & valve and household industry is just an example how a method based on a general model of technology could be used with the purpose to offer a rational effective approach to identification of competitive technological innovation especially in the case of SMEs. Although a certain knowledge of such industries and nanotechnology is at the base of this work a real study of the potential applications of nanotechnology will demand a much more in depth knowledge of technological operations of these industries and a more detailed knowledge of the possibilities of use on nanotechnologies. However the presented work gives a good idea about the potentiality of nanotechnologies to generate radical innovations in fabrication of conventional products addressed to a large consumer markets.

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