TECHNOSCIENCE

Science and Technology in Innovation

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ABSTRACT

This article describes a common activity of science and technology in the generation of new technologies called *technoscience*. That is possible because science and technology have the same physical nature being science definable as the study of single physical processes, and technology as the study on how to organize physical processes in a structure able to produce a physical effect exploitable for human purposes. In technoscience the structure of a technology may be modelled, as well as its change in forming a technology innovation. The study of technoscience shows that the knowledge of researchers or operators of a technology has the same nature. That in the frame of a link between science and technology in which science discovers phenomena exploitable for new technologies, and technology supplies to science the means to discover new phenomena. Furthermore, technoscience shows also that the creative process and the transfer of knowledge have the same nature either in science or technology, and that a knowhow is indispensable to operate both technology and experimental science. The most original results of the study of technoscience, is that creativity of scientific or technical nature is in many cases based, not only by combination of scientific or technical elements of knowledge, but also with the contribution of diversified casual elements coming from the living experience. Furthermore, adopting the Faggin idea about the nature of consciousness, knowledge is considered having the nature of qualia and of quantum information. For this reason, it cannot be cloned and it is impossible to verify that an acquired knowledge is exactly the same of the original one. Consequently, in the transfer of knowledge among researchers or operators of a technology, there are always differences. That may constitute new elements of knowledge useful for the creativity process. Artificial intelligence is considered a technology producing knowledge. However, from the physical point of view its results are in fact physical effects, and it is the looking to these effects that humans interpret them as results of an artificial intelligence. The study of technoscience may suggest applications in technology management and policies for technology innovations. The model of technology makes possible the simulation of the functioning of a technology and to help its development. The models of technology innovations may explain the relation between the number of R&D projects and formed new technologies, as well the description of a possible new technological innovation system boosting the formation of new technologies. Finally, technoscience may indicate how scientific research determines the potentiality of various technological sectors. In the appendix of the article are reported some mathematical models of technology and its innovation that may be useful for further developments of studies on technoscience.

Keywords: science, technology, technoscience, technology innovation, knowledge, creativity, knowhow, artificial intelligence, technology management, innovation policies.

CONTENTS

1. INTRODUCTION

This article is about fundamental aspects of science and technology showing that they have a common physical activity in the generation of new technologies, independently by any socioeconomic factor, and that may be called *technoscience*. This term is not a neologism but it has been introduced by the sociologist Bruno Latour in a study of the social relations between scientists and engineers in the society, and cited in his book with the title “Science in Action” (Latour 1987), We consider that this term may be used also to describe the common physical activity of science and technology and not only the sociologic aspects. In fact, we consider that science studies single physical phenomena or processes, while technology studies how these physical processes may be organized in a time-oriented structure producing a physical effect exploitable for human purposes. Such structure of a technology may be modelled, as well as its change in forming a technology innovation (Bonomi 2020). The study of technoscience shows that the knowledge of researchers or operators of a technology has the same nature. That in the frame of a link between science and technology in which science discovers phenomena exploitable for new technologies, and technology supplies to science the means to discover new phenomena. In the description of technoscience we consider in particular the role of knowledge as a link between science and technology, and defined as a typical knowledge concerning researchers and operators of a technology, different from that involved in theoretical science or in industrial, entrepreneurial and economic activities. Furthermore, technoscience shows also that the creative processes and the transfer of knowledge have the same nature in science and technology, and that a knowhow is indispensable to operate both technology and experimental science. Most of the aspects of technoscience, in particular concerning technology, have been published as working papers of IRCrES, a Research Institute on Sustainable Economic Growth of CNR, the Italian National Research Council, and reported after in two books “Technology Dynamics” (Bonomi 2020) and “Technology Innovation” (Bonomi 2023), published respectively in 2020 and 2023.

The article presents at the beginning a definition of technoscience based on physical definitions of science and technology. It is presented after the physical model of technology, and the role of knowledge in the models of technology innovation. It is then discussed the nature of knowledge, showing that in technoscience the process of creativity, the transfer of knowledge, and the formation and transfer of knowhow is of the same nature. It follows a discussion on the physical nature of artificial intelligence (AI) as a technology producing knowledge, concluding the article with the presentation of some applications of technoscience: the model of technology makes possible the simulation of the functioning of a technology and to help its development, the models of technology innovations may explain the relation between the number of R&D projects and formed new technologies, and a possible new technological innovation system boosting the formation of new technologies. Finally, technoscience may indicate how scientific research determines the potentiality of various technological sectors. In the appendix of the article are reported some mathematical models that may be useful for further studies on the development of technoscience.

2. A PHYSICAL DEFINITION OF TECHNOSCIENCE

A physical definition of technoscience may be based on the physical definitions of science and technology, already cited in the introduction, and that shall take account of the different approaches of these two activities.

2.1. A physical definition of science

Science cannot be defined completely as a study of the physical phenomena or processes. In fact, it is also the result of the development of a scientific thought since the ancient Greek philosophers.

However, in forming the modern science there was the introduction of use of measures, experiments and mathematics, leading to an experimental science that represents the scientific aspects involved with technology in forming technoscience. In this way science, from a physical point of view, may be defined as:

The study of single physical phenomena or processes

In this definition we consider a phenomenon an observable event, and a process as an entity depending on variables. Furthermore, we consider as physical processes also chemical and biological processes having them a physical nature. Of course, the importance of theoretical studies in science cannot be neglected, in particular in physics. However, the results of theoretical studies concerning phenomena or processes are considered scientifically ascertained through their confirmation by experiments. Furthermore, it shall be noted that science in building instruments and making experiments shall need a knowhow as in the case of operating a technology.

2.2. A physical definition of technology

There are many definitions of technology used in the economic and social studies but for a definition in terms of its physical nature we may cite a definition given in a book on the nature of technology (Arthur 2009):

A means to fulfill a human purpose.

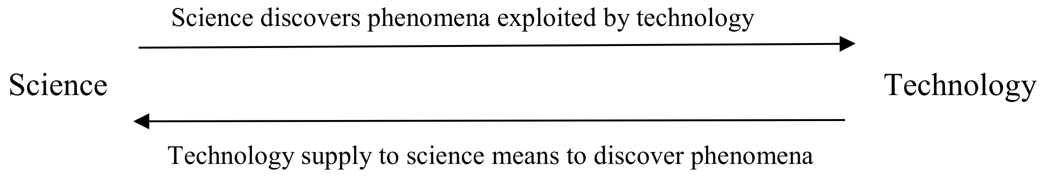
This definition is suitable for a physical definition of technology by completing it in this way:

A set of physical processes, organized in a time-oriented structure, resulting into a physical effect able to fulfill a human purpose.

This definition satisfies the fundamental aspects of technology being valid since the ancestral times of its existence, the physical nature of its activity, and includes also the economic or social aspects with the purposes for which its effects are exploited.

2.3. The physical definition of technoscience

Technoscience represents what it may be considered a common activity of science and technology from the physical point of view. Its objective is mainly the development of new technologies resulting by the links existing between the two. We may give a definition of technoscience activity considering the key relations existing between science and technology represented in the following schematic figure:



This figure represents a loop, joining the activities of science and technology, in which science discovers phenomena or studies processes that may be exploited by technology that, at the same time, supplies to science technological means to discover new phenomena or to study new processes. For these reasons, technology cannot be considered just as an application of science. In fact, in technoscience applied research cannot be considered just an application of scientific research to technology, but also an application of technology to scientific research. Furthermore, in this loop there are processes that have the same nature in either science or technology. These are creativity, that is the result of a combination of elements of knowledge for the generation of innovative ideas for both science and technology, the process of transfer of knowledge through information among researchers or among operators of a technology, and finally the knowhow, necessary to operate a technology and also to build instruments and to make experiments in science.

3. THE PHYSICAL MODEL OF TECHNOLOGY

The definition of technology as a structure of physical processes generating an effect exploitable for human purpose, makes possible the development of a general model of technology based on the structure of these processes. Actually, the direct modelling of technology with its physical processes is highly complex because of the high number and types of physical processes normally present in a technology and, for this reason, it has never really been attempted. A possible simplification of the structured set of physical processes of a technology appeared in studies carried out at the end of the '90 at the Santa Fe Institute in the frame of the science of complexity (Auerswald, Kauffman, Lobo, Shell 2000). The idea was to consider a technology as a set of technological operations in explaining the process of learning by doing. For example, the technology of heat treatment may be considered composed by three operations of heating, maintaining in temperature and rapid cooling (Bonomi 2023). Actually, these authors considered the concept of technological operation just for the measure of economic efficiency of a technology. It was the study of technology dynamics (Bonomi 2020) and of technology innovation (Bonomi 2023), that showed the physical nature of technology and of its technological operations. In fact, each technological operation may be considered a set of physical processes, and the set of the technological operations of a technology representing the set of all its physical processes. In this way the time-oriented structure of physical processes of a technology may be represented in terms of technological operations in a much simpler way than considering directly the physical processes.

The developed model of technology is based on its operations, considering their various parameters with their values, determining in this way all the possible configurations or recipes of the technology that may be represented in a space called *technological space*. If we associate to each configuration of a technology in this space its efficiency, it is obtained its *technological landscape* (Auerswald, Kauffman, Lobo, Shell 2000). Using this model, and taking account of the externalities influencing the efficiency of the technology, we may simulate the physical functioning of a technology, useful in searching optimal conditions of exploitation of the technology. The set of operations of a technology has a time-oriented structure that may be represented by a graph, and a graph may be described as a matrix. Using the various matrices describing the various technologies it is possible to represent technologies in a space called *space of technologies* (Bonomi, Marchisio 2016). The Hamming distance between a new and a preexisting technology with the same purpose represents the *degree of radicality* of the new technology, a measure of the physical difference between the two technologies with the same purpose. Finally, it is possible to define as a *technology ecosystem* the universal set of the technological operations in which each technology may be represented as a subset of this universal set (Bonomi 2023). In a Venn diagram of this universal set the radical degree of a new technology, in respect of a preexistent technology, is represented by the overlapping of their subsets. Lower is this overlapping higher is the radical degree of the new technology. It shall be noted that the representation of a technology as a subset does not take account of its structure. That means that two technologies with the same technological operations but different structure are represented by the same subset.

4. KNOWLEDGE IN TECHNOLOGY INNOVATION MODELS

From the model of technology, it is possible to consider a technology innovation a change of the structure of its physical processes, and then of the technological operations of a preexisting technology forming a new technology. For the modelling of technology innovation, it is also necessary to consider which are the conditions in which this change occurs. In technology dynamics it is considered that this change occurs in systems organizing in various ways fluxes of knowledge and capitals (Bonomi 2020). The flux of knowledge is considered the key aspect of the innovation while the role of the flux of capitals determines simply the possibility or not to finance the development of a technology by selecting the R&D projects proposals following the financing strategies. By consequence, the models of technology innovation are essentially based on the knowledge linked to the physical aspects of technology and its innovation. There are three types of structures organizing the fluxes of knowledge and capitals for technology innovations that are:

- The industrial R&D projects system
- The startup - venture capital (SVC) system
- The industrial platform system

These structures are not alternative but inclusive. From the physical point of view a new technology is formed in the R&D projects activity that is present, not only in industrial R&D, but also in the SVC and in the industrial platform systems (Bonomi 2020).

The R&D project system

It is considered for the model that the continuity of the R&D activity may be simulated by a certain number of cycles, in which there is cumulation of knowledge for new R&D projects proposals for a next cycle (Bonomi, Marchisio 2016). In the R&D system, the innovation is determined by the flux of knowledge, generated by the R&D activity, either in successful or abandoned projects, added with external knowledge, forming the available knowledge to generate innovative ideas for R&D projects proposals. New technologies, formed from the R&D activity, are seen as capital invested in R&D, either for successful or abandoned projects, entering in use with industrial capital, generating returns of investments and capital for new R&D projects. The meeting of the flux of available capital for R&D projects and that demanded by proposals, determines the R&D projects of the activity through a selection of the proposals, closing in this way the two loops of fluxes of knowledge and capitals.

The startup-venture capital (SVC) system

In this system the flux of knowledge is similar to that of the R&D system, considering that startups develop new technologies through R&D projects. The difference is in the flux of capitals. In fact, venture capital, differently from industrial capital, does not exploit the new technologies, but sells them reinvesting in new startups part of capitals obtained by the sale of the developed technologies (Bonomi 2019).

The industrial platform system

The industrial platform system may be considered derived from a general concept of platform system assuming various types of relations among its actors (Cicero 2017). This system is different from the previous systems as it is based, not on capital strategies, but on boosting the available knowledge and then of new technologies. This system is based on a platform organizing activities of generation of new technologies buying or financing the development of technologies proposed by firms, research laboratories and startups. The platform sells technologies to client firms in a continuous relation, receiving back knowledge from the use of the technologies, while platform supplies continuously to its customers improvements and new technologies. In this system there is among all actors a great exchange of knowledge boosting the generation of innovative ideas and then formation of new technologies. This system may also possibly evolve into a network of platforms forming a new technology innovation system (Bonomi 2020).

Concluding, further studies have also shown that, in a territorial technological system, the introduction of a successful SVC system, or of the industrial platform system, may improve the formation of new technologies in respect to the presence of only the industrial R&D system (Bonomi 2022b)

5. THE NATURE OF KNOWLEDGE IN TECHNOSCIENCE

Knowledge is a key factor in science and technology and then in technoscience. We have seen previously the role of knowledge in technology innovation. In technoscience it is considered that the role of knowledge is the same either for science or technology, and that concerning the process of creativity and of transfer of knowledge and knowhow. For a demonstration of this equivalence it is necessary to explain how it is formed knowledge in the human consciousness, that through the information reaching the human sensorial means, activating the neural structure of the brain, and perceived as knowledge in our consciousness.

5.1. The formation of knowledge

Although creativity and transfer of knowledge are processes of great importance, they are generally described only in terms of individual creativity (Dumbleton 1986) or of generative relations (Lane, Maxfield 1995), and the transfer of knowledge is considered in terms of information that has basically a physical nature. Actually, the detailed process with which an innovative idea is formed, or a knowledge is transmitted and perceived by a researcher or by an operator of a technology, is not until now physically explained. Currently innovative ideas and knowledge are considered involved in what it is called the consciousness. That opens the interrogative about the nature of consciousness, considered in fact a mystery also by experts developing AI (Russel, Norvig 2020). On the other side the nature of consciousness is of great importance in explaining the nature of knowledge, its transfer and the creative process, whether it is located or not in the brain, and whether it is possible to be formed in advanced AI machines generating what it is called an *artificial general intelligence* (AGI). An argument that will be discussed further in this article discussing AI. In fact, about the nature and possible location of human consciousness there are many theories of physical or metaphysical origin. However, none of these theories have been scientifically demonstrated, nor it would be possible to propose an experiment able to demonstrate or not their validity. Among all the available theories we find of interest the theory of Federico Faggin, a physicist inventor of the microprocessor when working at INTEL, and after studying the difference between artificial and human intelligence. For technoscience we consider only the part of Faggin's ideas about consciousness in fact included in his vast theory about life, intelligence and human nature (Faggin 2024a). This theory considers consciousness existing in a reality independent of space and time, and then not located in any part of the brain or of the body. The interest of this theory concerns its possible use in explaining the nature of qualia, the human perceptions of the consciousness characterized by the fact that is not possible to verify that this perception, for example the green colour perceived by looking to grass, is the same of that perceived by another person. The Faggin theory assumes that also knowledge has the nature of qualia. It is possible to make some considerations in support of the Faggin theory considering the physical process with which the green light coming from grass is transformed into a personal perception of a green colour in the consciousness. The light from the grass is represented by an electromagnetic wave with a specific frequency reaching the retina of the eye. Here it is transformed into physical signals reaching the brain through the optic nerve and activating the neural network in terms of a dynamics composed by physical, chemical and electrochemical processes. Such dynamics corresponds to the personal perception of the green colour as qualia in the consciousness. This perception may be considered as an epiphenomenon of the brain generated by the neural network. However, this epiphenomenon, and how the personal perception of the green colour occurs in the consciousness, do not have any physical explanation. This fact might indicate, as considered by the Faggin theory, the possibility that the consciousness could exists in a reality outside a physical representation, and then independent by space and time. Actually, it shall be noted that the complex relation between the brain and the consciousness is in fact largely unknown, and are unexplained in this relation processes such as the physical effects of drugs on the brain network and then in the consciousness, or the apparent existence of an unconscious activation of the neural network before a taken decisions becomes conscious. Nevertheless, the Faggin theory of consciousness gives an interesting, although not demonstrated and maybe not demonstrable, explanation of the processes of creativity and transfer of knowledge. For our discussions about the nature of knowledge, we adopt the following aspects of the Faggin theory concerning a redefinition of concepts such as information, knowledge and consciousness:

Information is considered of physical nature, such as air vibration, electromagnetic waves, etc. that may be transmitted or stored physically.

Knowledge is what it appears as a personal perception in the human consciousness from the neural activity stimulated by physical information reaching the human sensorial means.

Consciousness is an entity existing in a reality independent of space and time, not located in any part of the brain or of the body, in which it is perceived and formed the human knowledge.

In this way the acquisition of a knowledge would start with the emission of physical information, reaching the human sensorial means, transforming that in a neural activity of the brain, immediately perceived by the consciousness as a knowledge relative to the reception of information. Of course, it is possible also the inverse process in which knowledge in the consciousness may activate the neural network, and then the human sensorial means able to emit physical information that may reach another person that transforms information into his knowledge, or being simply stored physically.

5.2. The quantum nature of knowledge

Another aspect of interest of the Faggin theory on consciousness is the possible existence of a reality independent of space and time also in certain phenomena of quantum physics such as the superposition and entanglement, phenomena contrasting our macroscopic experience (Albert 1992). Faggin proposes also the idea that the conscious experience, and then knowledge, has a nature of quantum information (Faggin 2024b). This concept of quantum information has been introduced by studies on information-theoretical principles (D'Ariano 2016), and quantum information exists for example in quantum computers with the use of qubit. In fact, in normal computers it is used the bit that corresponds to a classic information of 1 or 0. On the contrary the qubit has, for the superposition, values corresponding to both 1 and 0, and a measure of it will give 1 or 0, while the other informative value is lost (D'Ariano 2024). For this reason, quantum information cannot be cloned as classic physical information composed by bits. Knowledge, being a conscious experience, will have then also a quantum information nature, and by consequence it cannot be cloned. That may have three consequences that in fact may be observed empirically. The first one is that a knowledge cannot be cloned and transformed into a physical information corresponding exactly to that existing in the consciousness. That may be observed in the practical experience of limits in the exactitude of knowledge transferred by information. The second one, having knowledge the nature of a qualia, and then being a personal perception, it is also impossible to verify that the knowledge obtained in the consciousness of a receiving person is exactly the same of the original transmitted knowledge. The third one is the fact that the transmitted knowledge, being always somewhat different, this difference may generate elements of knowledge that might be of interest in combination with other elements in the creative process.

6. CREATIVITY IN TECHNOSCIENCE

In technoscience the process of creativity is considered a combination of elements of knowledge of scientific, technical or of other nature in the individual consciousness of an inventor or of a researcher having a scientific innovative idea. In order to illustrate this process, we can give two important examples: the invention of PC by Steve Wozniak (Isaacson 2010) and the birth of the idea to develop the theory of relativity by Albert Einstein (RSI 2026).

Wozniak had the idea of PC from his knowledge of the microprocessor and the fact he worked at HP on a system connecting monitors to a centralized minicomputer. He had then the idea to connect a keyboard with a domestic TV apparatus through the microprocessor exploiting its logic and writing possibilities realizing in this way the first PC.

Albert Einstein had the idea to develop the theory of relativity when working in Bern at the Swiss Patent Office. During a trip on a tram, leaving a place with a watch tower, he thought what happens to the light coming from the watch if the tram would go away at a speed higher than the velocity of light, a question that started his work in studying the effects of the velocity of light and then developing the theory of relativity.

There are also many other examples of creativity based on casual and diversified elements such as for example the invention by Alfonso Bialetti of the coffeemaker Moka Express born by looking to a pot used in washing the laundry (Bialetti 1995), or the invention of the Morse alphabet by casual tapping of the inventor on a railing of a boat during a trip. I may add two personal examples of innovative ideas about a technology development and that of the model of R&D.

The first example occurred at the beginning of my carrier working in a group developing metallurgical technologies producing metals using as reducer a solution of calcium carbide in molten salty. I had in the office a colleague of another group of research working on surface treatments in molten fluorides such as boriding of metals to increase the surface hardness. From his fact I had the idea to use calcium carbide molten salt solutions, not for production of metals, but to diffuse carbon on the surface of steel to increase the hardness and this idea found industrial financing.

The second example concerns the ideas to consider the R&D activity in terms of fluxes of knowledge and capitals. This idea was born in reading a R&D management book (Dumbleton 1986) in which the R&D activity was described in terms of fluxes of products and processes and also of publications and patents. That gives the idea to consider these fluxes composed differently by knowledge and capitals.

All these examples show that the generation of an innovative idea, either for technical or scientific applications, occurs not only by combination of scientific or technical elements of knowledge, but also by contribution of elements of casual and diversified nature coming from living experience**.** The process that combines scientific and technical elements of knowledge with elements of casual diversified origin in the generation of an innovative ideas in the consciousness is mysterious. It is also unknown whether this process may be reproduced by AI, and whether AI may have available the enormous number of elements of knowledge generated by human living for this process.

7. TRANSFER OF KNOWLEDGE AND KNOWHOW

We discuss here the processes of transfer of knowledge and that of formation and transfer of knowhow following the Faggin theory of consciousness, and showing that in technoscience these processes are the same either in scientific or technical activities.

7.1. The transfer of knowledge in science and technology

Following the previous brief description of transfer of knowledge following the Faggin theory of consciousness, we give here more details including also the formation and transfer of knowhow. As previously described, the transfer of knowledge occurs through physical information constituted for example by air vibrations, electromagnetic waves, etc. that reach the human sensorial means and transformed into signals in the neural network of the brain, immediately perceived as a knowledge in the consciousness. This knowledge is not formed if the received information appears casual and not interpretable, although in certain cases it may appear as being a knowledge but not fully understood. There is also the inverse process in which the knowledge existing in the consciousness activates the neuronal network, and then the human sensorial means that transform knowledge into a physical information that may reach a researcher or an operator of technology that perceives it as knowledge in his consciousness. In other cases, this transmitted information is simply physically stored. As previously explained the knowledge transmitted and acquired from information cannot be exactly the same as the original knowledge, because of its quantum nature hindering to be cloned. As already told this difference in knowledge may constitute a new element of knowledge useful in the creativity process.

7.2. The formation and transfer of knowhow as a knowledge

Following the Faggin theory, a knowhow is acquired directly from technological activities, or in making scientific experiments., generating a neural activity, and perceived and cumulated as a knowhow, having it the nature of a knowledge, in the consciousness of a researcher or of an operator of a technology. Because of the importance of the activity in forming a knowhow, its transfer from an expert to a newcomer through information is only partial, and a full acquisition of knowhow by a newcomer necessitates also imitation and direct experience to complete a knowhow in his consciousness. As in the case of transfer of knowledge, the knowhow acquired by the newcomer cannot be exactly the same as the knowhow existing in the consciousness of the expert. This difference, as in the case of the transfer of knowledge, may be useful as element to improve the knowhow of a technology. An additional explanation of knowhow in terms of technological operations may be found also using the model of technology (Bonomi 2020).

8. KNOWLEDGE AND ARTIFICIAL INTELLIGENCE

AI may be considered a technology producing knowledge useful for either scientific or technical activities, and it may be described as a physical process with its potentialities and limits.

8.1. Artificial intelligence as a technology

AI may be described as any technology as a set of physical processes, and operated with a physical input of instructions, obtaining a physical effect representing the wanted results. The basic technological components of an AI machine consist in a great number of electronic microswitches organized in a certain way in the machine, each able to establish or not a difference of potential, corresponding to the logic values of 1 or 0 used in the development of the software necessary for the functioning of the machine. Practically an AI machine is a deterministic system in which the obtained result is in fact a physical effect originated by the physical configuration states of the microswitches existing in the machine. For these reasons, the machine owns a virtual intelligence, while the real intelligence is that of people that have developed the software and designed the hardware of the machine (Faggin 2024a), and that of people that have introduced the right instructions and considered as intelligent results the physical effects produced by the machine. From this point of view the affirmation that AI produces knowledge is erroneous as in fact knowledge is that obtained by humans looking to the physical effects produced by the AI machine. However, it shall be noted that the question of the real existence or not of AI is not considered of interest by developers of AI that pay attention essentially to show its possible applications (Russel, Norvig 2020). Furthermore, the psychological relation of people with AI machine in looking to the results is quite complex, and it is observed that the interpretation of results in terms of AI persists also in people convinced of the deterministic nature of the machine and inexistence of an artificial consciousness. In every case, following the Faggin theory of consciousness, an AI machine cannot have physically an intelligence like humans, and the development of a consciousness in a more complex AGI machine, based on electronic microswitches, and then with a physical deterministic nature, seems impossible.

8.2. Potentiality and limits of artificial intelligence

There is great potential by combining AI with other technologies in order to increase their efficiency. Because this application is valid for any technology, there is a great innovative potential in the development of AI and of its applications. It is not the aim of this article to discuss all the potentialities of AI, and we consider only the limits of use of AI dictated by its physical nature. The first limit consists in the fact that AI cannot have, differently from humans, any auto-critical judgment about its results. In other words, it is unable to consider its results in the frame of the complex reality in which these results may be used, that because, being a deterministic machine, it takes account only of available information it has had access, and not by all the various knowledge cumulated by humans during their life experience. The consequence is that the results of AI shall be always supervised for their applications or use for the management of activities. Furthermore, AI has limits in technical or scientific creativity, as it does not have the access to casual and diversified elements of knowledge, combined with scientific or technical elements, as discussed previously, and acquired currently by humans during their living. Another limit to AI creativity may be found in the difference of thinking of an inventor in respect to that of the scientific community that is at the base of the sources of information for AI (Basalla 1988). That was the case of Guglielmo Marconi, and his success in the transmission of signals based on electromagnetic waves beyond the horizon. Actually. the relation among inventors of new technologies, based on scientific discoveries, and the opinion of the scientific community may be quite complicated as sometimes a development based only on trial-and-error may lead to important innovations against the opinion of scientists based on available scientific knowledge. That is possible because scientific knowledge is never definitive, and the idea that in the outer space there is a layer reflecting electromagnetic waves was too far from scientific considerations at that time. Consequently, the idea of Marconi to verify the possibility of transmissions beyond the horizon would not be possible by the creativity of a hypothetical AI machine, based on the scientific knowledge available at that time. The previous observations however do not demonstrate that AI cannot use differentiated casual elements of knowledge, but the difficulty of AI to have access to the enormous amount of data corresponding to the elements of knowledge linked to human living, and how some casual differentiated elements of knowledge may be integrated with scientific and technical knowledge to generate an innovative idea as occurs in human creativity.

Concluding we may cite finally that AI raises also ethical aspects in its use and development that shall be considered (Russel, Norvig 2020), and dangers in its use consisting in the transfer of human rationality to machines, knowing results but not having any idea how they are obtained. That may result in a dangerous situation in the case of unavailability of AI without any idea how substitute it. In fact, AI shall be considered a technology to increase the human intellectual capacities and not to substitute them.

9. APPLICATIONS OF TECHNOSCIENCE

Technoscience may have some applications in technology management and in policies for technology innovations independently by any socioeconomic factor. We consider here the simulation of functioning of a technology, the use of the physical degree of radicality of a technology to help its development, the relation between number of R&D projects and formed new technologies, the development of a new technology innovation system able to boost the generation of new technologies, and how scientific research may influence the development of certain technological sectors. For the development of these applications there is in the appendix of the article the mathematical descriptions of the model of technology, the model of externalities influencing the efficiency of a technology, and the model of the R&D activity. Such models may be informatized making easier their use in further studies on applications of technoscience.

9.1. Simulation of functioning of technologies

The model of technology may find an application in the simulation of functioning of a technology. For that it is necessary to describe the structure of the technology in which the operations are sufficiently detailed in order to have available all the necessary parameters for its functioning. Choosing the range of values or choices of the various parameters, it is possible to have the technological space of the technology, constituted by points representing the various operative configurations or recipes of the technology. If we associate to each configuration the value of its efficiency, we obtain the technological landscape of the technology. All that may be represented mathematically as reported in Appendix A1 of the article. In this way it is possible to explore the efficiency of the various configurations of the landscape finding optimal conditions of functioning. The technological landscape has been object also of theoretical studies concerning its exploration in search of an optimum and about its shape (Auerswald, Kauffman, Lobo, Shell 2000). For example, there is a study about the search of optimal conditions of efficiency (Kauffman, Lobo, Macready 2000), or discussing the search in term of adaptive explorative walk (Lobo, Macready 1999), as well as a study on recombinant search in the invention process (Fleming, Sorenson 2001). Technological landscapes have been even considered, not necessarily as mathematical tools, in discussing certain aspects of technology management (Strumsky, Lobo, 2002), and in technological search in landscapes mapped by scientific knowledge (Fleming, Sorenson 2004).

It shall be noted that the values of efficiency of the technological landscape depends on externalities that may be represented by scenarios of variables with their values in a specific range. It is possible to establish a mathematical description of each scenario modelling the variables as the parameters in the technological space. Such mathematical modelling of the externalities of a technology is reported in Appendix A2 of the article. In this way it is possible to have various technological landscapes, and to make a search of the optimal conditions for a certain number of scenarios of externalities of the technology. Another aspect concerns the fact that there are various types of efficiency of a technology. Beside the economic efficiency, represented by the inverse of costs of the technology, we may consider other types of efficiency such as the energetic or environmental efficiency. The type of efficiency influences of course the aspect of the technological landscape. In the case of the economic efficiency, it is relatively simple to build the landscape as costs of each configuration may be expressed as a function of the various elements of costs concerning the parameters. For other types of efficiency, it may be necessary to make measurements or even experiments to have the efficiency of the configurations for the landscape. Finally, it shall be considered the interest to have an optimal configuration that is a compromise among various types of efficiency by confronting the corresponding technological landscapes. Knowing the various landscapes of the various types of efficiency, it is possible to find an optimum compromise among the various optimal configurations. A simple example of search of an optimal configuration confronting the economic and environmental efficiency is reported in an example in the Appendix A1.8 of the book on technology dynamics (Bonomi 2020).

9.2. Radicality of technology and the innovation process

We have seen in defining the space of technologies that the distance between a new technology and a preexistent technology with same purpose represents its physical degree of radicality. A degree that is dependent on the change in the technological operations necessary to obtain the new technology. In this way, in a development of a new technology, it is possible to identify the various new technological operations that are necessary for the innovation. Such operations have normally an experience of use in other technologies, and it is then possible to obtain useful information from these experiences that may help the development work for the new technology.

9.3. Relation between R&D projects and new technologies

The model of R&D may be used to simulate the R&D projects activity and the formation of new technologies. That is possible by the use of valid values for the parameters of the mathematical model reported in Appendix A3. The parameters that are necessary to make calculations with the R&D model are:

N_o: number of initial projects in the R&D activity
N: number of projects of the R&D activity
p: average number of information packages generated by one project of the R&D activity
f : rate of fading effect of number of information packages of past R&D projects
E: rate of external information contributing to the total available information
m: combinatory number of information packages necessary to form an idea for a R&D proposal
s: rate of selection of possible combinatory ideas for proposals from available information
t: rate or R&D proposals selected for R&D projects
v: rate of generation of new technologies from number of R&D projects
r: rate of success of new formed technologies
n: number of past cycles of R&D activity considered for the calculations

The main calculation results of the model are: the number T of new technologies entering in use, and the number S of new successful used technologies. In order to avoid any influence of socioeconomic factors on the calculations, it is assumed in general that all the R&D projects proposals are financed and then $t = 1$. Of course, the rate t of the model represents in every case the impact of the capital strategies in the model of R&D.

Most of the values of the parameters of the model represent data averages or indications observed from experience, and may be also the result of statistical studies, taking account of the different conditions of the R&D activity. In a previous working paper about the applications of the mathematical model of R&D (Bonomi 2017), it is reported a discussion about the obtention of the values for the parameters indicated by experience or by statistical studies. These values of the parameters of the R&D model have been used for various calculations showing some interesting results, in particular about the relation between the number of formed technologies as a function of the number of projects of the R&D activity. This relation is not continuous, and there is a threshold separating conditions of absence of formation of new technologies from conditions of autocatalytic growth of formation of new technologies, that because of the cumulation of knowledge during the R&D activity. This threshold is determined by a critical number of initial projects of the R&D activity. That may be demonstrated by studying the number of formed R&D proposals from a variable initial number of projects of the R&D activity, generating knowledge and then R&D projects and new technologies, following the increase of the number of cycles simulating the R&D activity. In fact, for a low number of initial R&D projects, the formation of knowledge is insufficient to support the continuation of formation of R&D proposals, or to have an average sufficient number of projects to contrast the abandonment rate of unsuccessful projects. The consequence of a low number of R&D projects is the arrest after a certain number of cycles of the formation of proposals and then the arrest of the R&D activity. On the contrary, a high number of initial R&D projects cumulates knowledge following the number of cycles, with an autocatalytic effect of generation of R&D projects proposals, R&D projects and then new technologies. The result of these calculations corresponds to the empirical evidence of technology stagnation or decline in presence on a low R&D activity in terms of projects.

A similar result is obtained by calculating the minimum number of initial R&D projects N_o necessary to form at least one new technology or one successful technology, within a maximum number of cycles (Bonomi 2017). That as a function of the parameter s indicating the rate of selection of innovative ideas from available information for R&D projects proposals, a parameter that may be considered a measure of the efficiency of the R&D activity. In this case it is obtained a figure representing the dependence of N_o as a function of s, showing the formation of two curves with decreasing needed values for N_o with the increase of s. The lower curve corresponding to the formation of new technologies, and the higher curve the formation of successful technologies (Bonomi 2017). The two curves separate the diagram into three areas, the lower corresponding to conditions of absence of formation of new technologies and then of technology decline, the area above the higher curve correspond to conditions of formation of many new successful technologies, and then of technology development. In the intermediate area between the two curves there is formation of new technologies but not of successful technologies, and that may indicate conditions of technology stagnation (Bonomi 2017).

These studies show that the model of R&D may be used successfully, after determination of valid values of parameters, for technology management and innovation policies. In technology management it is possible to study the formation of new technologies from the R&D activity, and in policies for technology innovation the determination of the thresholds of R&D activity in a territory that allows a technology development from a situation of technology decline. Concluding, beside its interesting results, it shall be noted of course that the model is only a rough simulation of the real R&D activity, and the relations among the various parameters may be more complex. For example, the parameter v representing the rate of formation of new technologies from the R&D projects depends also on the degree of radicality of the developed innovations. In fact, it is known that the development of radical technologies has a lower probability of success in respect to incremental technologies, and that open further developments of the model. Nevertheless, the model appears of interest in a primary use and may give results in accord with empirical observations of the R&D activity.

9.4. A new technology innovation system

We have already seen as the introduction in a territory of the SVC system, and in particular of the industrial platform systems, may improve the formation of new technologies in respect to the presence of only the industrial R&D projects system (Bonomi 2022b). The development of new applications of AI, and the greater need of new technologies for the solution of environmental problems (Bonomi 2022a), would require a new technology innovation system boosting the formation of new technologies. That may be obtained in a greater measure by boosting the availability of knowledge instead of developing strategies based on capitals. It is possible to think to a new technology innovation system of a territory based on the formation of a network of industrial platforms, each specialized in a particular technological sector, and firms focusing activity on the conception of the product using technologies supplied by the platforms (Bonomi 2020). For the formation of such system, it is necessary to transform the present innovation system, based on a distributed innovation (Haour 2004), into a system in which firms producing technologies are transformed into platforms, and firms making products limit their activities to the concept of the product using available technologies supplied by the platforms. On the other side, firms, research laboratories and startups will offer new available technologies or their developments to the various platforms of the network. In this system there is a great exchange and generation of knowledge among its actors boosting in this way the formation of new technologies.

9.5. Scientific research and technological sectors

Considering how scientific research may be oriented to boost the generation of new technologies, we may look to certain key aspects of technoscience. One of these aspects concerns the creativity process, in which innovative ideas are considered the result of a combination of elements of knowledge and increasing with its availability. That would favour the technological sectors in which scientific research could make available a great number of possibilities to discover new exploitable phenomena or processes. Another key aspect is the potentiality of scientific research to discover new exploitable phenomena in a particular scientific discipline. A third key aspect concerns the technological sectors that are involved in a great increase of possible applications, then demanding to scientific research a support for new technologies. Concerning the aspect of the existence of a great number of possible exploitable elements of knowledge, we may cite the sector of nanotechnologies that is based on the existence of a great number of materials reduced in particles or in very thin layers with new properties exploitable for new technologies, and also the sector of synthetic biology favoured by availability of a great number of molecules, either of natural or synthetic origin, that may be biologically active, and useful for various biotechnological applications. Concerning the discipline offering a major potentiality to discover new exploitable phenomena there is quantum physics, a new discipline that is still under development. Finally, concerning technological sectors with a great need of new technologies, and then of scientific research, we may cite AI for its numerous applications in increasing the efficiency of technologies, and the environmental sector needing new technologies for the solution of problems of pollution, depletion of resources and global warming.

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APPENDIX

Mathematical modelling

It shall be noted that these models are essentially a rough representation of the complex aspects of technology and of its innovation. However, they may be improved on the base of the considered assumption and, although the used simplifications, they may give valid interpretations of the reality of these activities.

Appendix A1

In this first appendix we present the mathematical description of a model of technology based on concepts such as: the technological space and the corresponding technological landscape (Auerswald, Kauffman, Lobo, Shell 2000), the space of technologies (Bonomi, Marchisio 2016) and the technology ecosystem (Bonomi 2023).

The technological space

From the mathematical point of view, a technology may be described considering by a set O composed by N operations o_i leading to the definition of the set $O = \{o_i, i = 1, ..., N\}$. On the other side each operation o_i is characterised by a set M_i of M_i specific parameters p_{ij} and then: $Mi = \{p_{ij}, i = 1, ..., N ; j = 1, …, M_i$ in which p_{ij} represents the jth parameter associated with the ith operation o_i. The total number P of parameters characterising a technology is given then by:

N

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

The parameter p_{ij} may assume a set S_{ij} of different values or choices and $S_{ij} = \{s_{jik}, i = 1, ..., N ; j = 1, \ldots, Mi ; k = 1, \ldots, S_{ij}\}$ in which S_{ij} indicates the cardinality of the set S_{ij}.

The N operations cannot be considered simply a set, in fact they have normally a specific temporal sequence that may be represented by a time-oriented graph. Indicating with $\boldsymbol{E}$ the set of events determining the start or/and ending of the operations and, as previously indicated, 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*:

$$\tau = (\boldsymbol{E}, \boldsymbol{O}) \quad (2)$$

In which $\boldsymbol{E}$ represents nodes and $\boldsymbol{O}$ the time-oriented arcs of the graph.

Taking account that, in our model, each operation can be associated to more than one parameter as indicated in equation (2), an operation, such as in the example of heating in a heat treatment, can be associated not only to a parameter such as the final reached temperature but also to a specific velocity of heating. Being N the number of operations, and from equation (1) P the total number of parameters we have: $P \geq N$, and when $N = P$ each operation is characterised by only one parameter.

Considering a specific technology with a set of N operations corresponding to a total of P parameters, we can define as *technological recipe* the specific configuration ω obtained attributing a specific value or choice to each of the P parameters. The set Ω of all the possible configurations of a technology is given by $\Omega = S_{11} \times S_{12} \times ... \times S_{1M1} \times ... \times S_{NMN}$ in other terms we have:

$$\Omega = \{\omega_l, l = 1, ..., \prod_{i=1}^{N} \prod_{j=1}^{M_i} S_{ij}\} \quad (3)$$

The number of configurations $|\Omega|$ is given by:

$$|\Omega| = \prod_{i=1}^{N} \prod_{j=1}^{M_i} S_{ij} \quad (4)$$

Should be $S_{ij} = S$, $i = 1, \ldots, N$ and $j = 1, \ldots, M_i$ we have $|\Omega| = S^P$.

We may note that the number of configurations varies exponentially along with the number of values or choices for the parameters, and even with a small number of parameters the number of possible technological recipes is 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 in a simplified heat treatment technology, 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 o2 of cooling we may have $M_2 = \{p_{21}\}$, corresponding to a free cooling to a final temperature indicated by parameter p_{21}. Now considering there are two possible heating temperatures and only one value of velocity of heating we have $S_{11} = \{s_{111} , s_{112}\} = 2$ and $S_{12} = \{s_{121}\} = 1$. At the same time should be two the final cooling temperatures we have $S_{21} = \{s_{211} , s_{212}\} = 2$. The number of configurations ω present in the set Ω will be of four: $|\Omega| = S_{11} x S_{12} x S_{21} = 2x1x2 = 4$. 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: $d (\omega, \omega') = d (\omega', \omega)$. In the same manner we may define the set N_δ of neighbours of a recipes $\omega \in \Omega$ defined as the number of configurations ω' existing at distance δ from ω as follows:

$$N_\delta(\omega) = \{\omega' \in \Omega \mid d (\omega, \omega') = \delta\} \quad (5)$$

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 parameters is characterised by S_{ij} values or choices, the dimensionality of the technological space will be:

$$|N_{\delta=1}| = \sum_{i=1}^{N} \sum_{j=1}^{Mi} (S_{ij} - 1) \quad (6)$$

Should the parameters have all the same number S of values or choices the dimensionality of the technological space will become: $2|N_{\delta=1}| = (S - 1)P$. In this case the geometrical representation of the technological space becomes a hypercube of dimension $|N_{\delta=1}|$

The technological landscape

Mathematically the *technological landscape* may be defined mathematically indicating with Θ the corresponding value of efficiency to a specific recipe ω of set Ω:

$$\Theta : \omega \in \Omega \to R^+ \quad (7)$$

This mapped space is characteristic of the specific structure of operations and instructions constituting a technology and depending of course on the used type of efficiency. 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. 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 is given by:

$$\Theta(\omega) = \sum_{i=1}^{N} \theta_i (o_i, o_l) \quad (8)$$

This way of calculation of the total efficiency of a recipe as sum of efficiency values of single operations is easily carried out in the case of technical efficiency such as energy, purity, pollution abatement, etc. In the case of economic efficiency, as we have previously noted, if we define it as the inverse of cost of each operation, the equation (8) is not valid, as the sum of the inverse of operational costs does not give the total economic efficiency. It is possible, and maybe preferable, to use directly the cost of operations with its sum constituting the total cost of a recipe, and optimal conditions in the technology landscape determined by the minimum of these costs. In such case the total economic efficiency $\Theta(\omega)$ of the technology with configuration ω composed by N operations will be given by:

$$\Theta(\omega) = 1 / \sum_{i=1}^{N} c_i (o_i, o_l) \quad (9)$$

The total cost C of the recipes by:

$$C(\omega) = \sum_{i=1}^{N} c_i (o_i, o_l) \quad (10)$$

The space of technologies

Let us consider a set of technologies *T,* each technology belonging to *T* characterised by M operations chosen from a set *O* of N different operations involved in all the considered technologies. 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':

$$d(\tau, \tau') = \sum_{i=1}^{M}\sum_{j=1}^{N} |T_{ij} - T'_{ij}| \quad (11)$$

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 may name *space of technologies*. Furthermore, it is possible to define a set N_δ of the neighbouring technologies of the set T that are between the distance δ as $N_\delta(\tau) = \{\tau' \in T \mid d(\tau, \tau') = \delta\}$. The number of all the technologies τ present in 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. Comparing two matrices, one representing a new technology, and the other a preexistent technology with the same purpose, it is possible to determine their Hamming distance corresponding to the number of changes that shall be made to make equal the two matrices.

The technology ecosystem

From the mathematical point of view in the technology ecosystem we may define a technology as a set T composed by a number N_t of o_{ti} operations: $T = \{o_{ti}, ti = 1, ..., N_t\}$. It is also possible to define a set L including all the M_l technologies T_{vi} having the same purpose representing a space of technologies: $L = \{T_{li}, li = 1, ... M_l\}$. In the set L the technologies T_{li} are also describable as a set T_{li} composed by a number of N_{tl} of its operations o_{tsi}: $T_{li} = \{o_{tli}, tli = 1, ..., N_{tl}\}$. Finally, we may consider a universal set U composed by the number O of all o_i operations used by all technologies considered in the universal set: $U = \{o_i, i = 1, ..., O\}$. We may then consider the various relations existing between the sets T, L and T_{si} with the universal set U. First of all, as technologies are composed by technological operations, the various sets T are subsets of the universal set U i.e. $T \subset U$. For the same reasons, also the various spaces of technologies L having the same purposes are subsets of the universal set U i.e. $L \subset U$. By consequence, the various technologies with the same purpose owning to the various corresponding sets L will be sub-subsets of the universal set U. Finally, it may be considered that two technologies may have in part the same type of technological operations. Considering two technologies, not necessarily with the same purpose, described by the sets of operations respectively T_i and T_j,, the part of common operations may be indicated as the intersection $T_i \cap T_j$. On the other side it is possible also that all the operations of a technology represented by the set T_w will be completely included in the technology represented by the set $T_z \subset T_w$.

Appendix A2

In this second appendix we present the mathematical description of externalities and intranalities of a technology (Bonomi 2020).

The mathematical description of externality of a technology takes account of external variables with their parameters, values or choices analogously to technological operations with their parameters, values or choices made for the mathematical model of technology, then forming specific configurations of the externality of a technology. Considering the set V composed by B external variables v_i : $V = \{v_i, i = 1, ..., B\}$. Each external variable v_i is characterised by a set R_i of R_i specific parameters: $R_i = \{q_{ij}, i = 1, .., B ; j = 1, \dots, R_i\}$ where 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:

$$Q = \sum_{i=1}^{B} R_i \quad (12)$$

The parameter q_{ij} may assume a set F_{ij} of values or choices: $F_{ij} = \{f_{jik}, i = 1, ..., B ; j = 1, \dots, R_i ; k = 1, \dots, F_{ij}\}$ in which F_{ij} indicates the cardinality of the set 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 are given by: $\Gamma = F_{11} \times F_{12} \times ... \times F_{1R1} \times ... \times F_{BRB}$. In other terms we have:

$$\Gamma = \{ \gamma_l, l = 1, ..., \prod_{i=1}^{B} \prod_{j=1}^{Ri} F_{ij} \} \quad (13)$$

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

$$|\Gamma| = \prod_{i=1}^{B} \prod_{j=1}^{Ri} F_{ij} \quad (14)$$

Should be $F_{ij} = F$, $i = 1, \dots, B$ et $j = 1, \dots, R_i$ we have $|\Gamma| = F^R$.

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:

$$G = |\,\Gamma\,| x |\,\Omega\,| \quad (15)$$

in which $|\,\Omega\,|$ represents the number of all possible recipes existing in the 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 in account both of the number of possible recipes and of the number of configurations of external variables that influence the efficiency of technology.

Beside the influence of externalities on the efficiency of a technology there is a minor further effect called *intranality*. It represents the fact that, changing the conditions of an operation, in order to improve its efficiency, that may influence the efficiency of other operations of the technology, and then its overall efficiency (Auerswald, Kauffman, Lobo, Shell 2000). This effect depends on the type the involved technology operations and cannot be object of a general model as that for externalities, but in certain case it shall be accounted in the simulation of functioning of a technology. Although it is not possible a modelling, it is possible to explain how to identify the possible existence of intranalities looking to a matrix made with the operations and the parameters of the technology, considering the relations among operations and parameters as follows:

Concerning intranalities, from the mathematical point of view, and with the notations used for the model of technology, it means that if we modify values of parameters of an operation o_i, the efficiency θ_i of operation o_i will depend on values or choices s_{ijk} of its parameters p_{ij}, but possibly also on values or choices of parameter of other operations o_j, with $j \neq i$. We may easily represent the intranality 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 parameters 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 $j = 1, \ldots, R_i$ then assuming for each position a value for example of 1 whether influence of the specific instruction or external variable on the efficiency of the specific operation exists or 0 otherwise:

o_1 o_2 ...... o_N
p_{11} ....
p_{12} ....
....
p_{NMN} ....
q_{11} ....
q_{12} ....
....
q_{BRB} ....

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 parameters and external parameters nodes to operations nodes. This graph represents the global interactions, external and internal, 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.

Appendix A3

In this third appendix we present the mathematical description of model of the R&D projects system (Bonomi 2017) with the considered assumptions for the fluxes of knowledge and capitals. The assumptions concerning the flux of capitals are:

- The R&D activity is constituted by a certain number of R&D projects in relation with the related R&D investments.
- The R&D activity generates a certain number of new technologies coming from successful R&D projects while the other projects are abandoned.
- Part of the new technologies becomes successful technologies producing a favourable economic effect.

- New technologies enter in use with industrial capitals producing returns of investments.
- Industrial capital makes available investments for new R&D projects following its strategies.

The assumptions concerning the flux of knowledge are:

- The knowledge involved in the R&D activity is considered determined quantitatively in term of numbers of information packages formed by either successful or abandoned R&D projects.
- The overall knowledge available from R&D activity after each cycle, includes also that of past cycles reduced by a fading effect, and it is increased by a fraction due to external contributions from scientific, technical or other origin.
- The number of potential innovative ideas for the next cycle is obtained, from the total number of available information packages, by a combinatorial calculation considering that the generation of a potential innovative idea results by a combination of an average number of information packages.
- The number of R&D projects proposals is obtained by choosing the valid innovative ideas, among all the calculated potential ideas, and the rate of this selection is considered a measure of the *innovation system efficiency* (ISE) in the generation of R&D project proposals.
- The number of R&D projects feeding a cycle results from the selection of the presented R&D project proposals, that on the base of the available R&D investments and selection criteria. In this way are closed both the knowledge and capital fluxes of the two loops of the cycle.

Starting from these assumptions it is possible to develop a mathematical model of R&D as follows:

The mathematical simulation considers that the R&D activity of each cycle is composed by N projects that may be calculated considering the flux of knowledge. We shall, first of all, define a measure of knowledge generated by R&D projects in term of number of information packages. For this purpose, we consider that each R&D project generates an average number *p* of information packages and that total available information packages result of the sum of packages generated by the cycle plus the information packages of previous cycles reduced by the fading effect *f*. Such total number of packages shall be increased by a contribution taking account of information packages coming from scientific, technical and other information composing an external available knowledge. The total number of information packages I_T available for generation of innovative ideas and then R&D project proposals may be calculated mathematically by the formula:

$$I_T = \{N_L p + \sum_{i=1}^{n} I_i(1-f)\}(1 + E) \quad (16)$$

in which we have:

I_T : total number of information packages available for new innovative ideas after the last cycle
N_L : number of R&D projects in the last considered cycle
p : average number of information packages of each R&D project
n : number of past cycles
I_i : number of remaining information packages of past cycles from i = 1 to i = n)
f : rate of fading effect
E = fraction of added information packages by external knowledge

It shall be noted, about the fading effect that for remaining information packages of past cycles we intend that the initial information packages of a cycle are reduced by fading effect *f* at each successive cycle before the last one, and with $f = 0$ the fading effect is not present and with $f = 1$ there is a complete loss of past information packages. The generation of potential innovative ideas is obtained by a combinatory calculation considering an average number of available information packages and number of combining information packages necessary to have an innovative idea and expressed by the following formula:

$$G = I_T(I_T - 1)/m \quad (17)$$

in which we have:

G : number of potential ideas for innovations
I_T : total number of information packages available for potential innovative ideas after the last cycle
m : combinatory number of information packages necessary to generate a potential innovative idea

In fact, such number G of potential ideas are a simple combinatory result, not considering any validity about specific combinations, and contains necessarily in fact a large number of invalid or even absurd combinations. The innovative system makes then a selection of the valid innovative ideas. The number P of effective new ideas becoming R&D research proposals may be obtained by considering a rate factor *s* applied to the number G of potential new innovative ideas, such rate represents a measure of the *innovative system efficiency* (ISE) already cited, obtaining the relation: $P = sG$. A last selection occurs in comparing R&D project proposals budgets with available R&D investments and we may define a rate *t* determining the number N of R&D proposals that can effectively become R&D projects following the relation: $N = tP$.

In conclusion we may express the total number N of R&D projects carried out in a cycle as a function of generated packages of information I_T by the previous cycle combining equation (17) with previous definitions of $s = P/G$ and $t = N/P$ we have:

$$N = tsI_T(I_T - 1)/m \quad (18)$$

Considering the calculated number N of R&D projects carried out in a cycle, the number T of new technologies entering in use will be determined by a selection rate *v* following the formula $T = vN$, and considering now the successful number of new technologies S, they will be the result of a selection rate *r* on the number T of new technologies entering in use following the formula $S = rT$. This obtained value of S represent the final result of calculation with this simulation model. All the variables and parameters used by the R&D model are recapitulated in the following lists:

List of variables
I_T total number of information packages available for new innovative ideas after the last cycle
N_L number of R&D projects in the last considered cycle
I_i number of remaining information packages of past cycles
G number of potential ideas for innovations
P number of R&D project proposals
N number of financed R&D projects of the cycle
T number of generated new technologies
S number of formed successful technologies

List of parameters
p average number of information packages of each R&D project
n number of past cycles
f rate of fading effect
m combinatory number of information packages necessary to generate a potential innovative idea
E fraction of added information packages by external knowledge
s fraction of potential ideas becoming R&D project proposals
t rate or R&D proposals selected for R&D projects
v rate of generation of new technologies
r rate of success of new technologies

It shall be noted that this model of the R&D activity, represents a physical model of generation of new technologies, based essentially on the generation and use of knowledge in proposing new R&D projects. The role of the flux of capitals is limited to supply the available capitals for R&D to finance the selected R&D proposals, without entering in the strategies concerning the amount of available capitals for R&D, and selection of the R&D projects to be financed.